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THE MINICOMPUTER: AN EDUCATIONAL TOOL

by

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THE MINICOMPUTER: AN EDUCATIONAL TOOL

BY

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THESIS

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1. INTRODUCTION

1.1 Introduction to Long-Range Planning

This study can be likened to a journey. The traveler prior to his departure is well advised to study his guide books before launching any adventure. Our guidebook for this educational exploration is: PRELIMINARY REPORT OF LONG-RANGE PLANNING COMMITTEE FOR THE URBANA-CHAMPAIGN CAMPUS, THE UNIVERSITY OF ILLINOIS, URBANA-CHAMPAIGN CAMPUS, OFFICE OF THE VICE CHANCELLOR FOR ACADEMIC AFFAIRS, FEBRUARY, 1970.

In Section 1.2 we summarize relevant portions of its contents and in Section 1.3 we comment briefly on these guidelines.

1.2 Summary of Educational Guidelines

In this report, the committee stated that the chief functions of the University, as the state's educational system developed, were the following:

1. Teaching, research and scholarly and creative activity in the fundamental fields of learning

2. Teaching and research in professional and occupational areas closely dependent on the fundamental fields of learning

3. Liberal education of able young men and women who do not intend to become highly trained specialists and, to the extent possible, of students aiming toward specialized or professional training

4. Vocational training in fields which are clearly of substantial and wide importance to the state and nation, especially those which require four-year programs including sound preparation in the fundamental fields of learning and which the University is uniquely or best fitted to provide

The fundamental fields of learning were defined as mathematics, the biological and physical sciences, the humanities, the fine arts, and social

sciences. These were defined as fundamental "not only because they have long been studied for their own sake but also because they underlie most fields of applied knowledge." In the fundamental fields, it was contended, basic research is the source of every advance in the applied fields.

Predictions of the growth in the size of the college-age population, and the proportion of that population demanding college education through the most advanced degrees, are conservatively estimated to increase so that the need to provide college education to some 60 to 65 percent more students in 1980 than in 1969. Further, it is likely that the proportion of Illinois students who are candidates for Master's and Ph.D. degrees will increase more rapidly than those enrolled for the baccaluareate.

At the present rate of technological and scientific development, the store of knowledge doubles every ten years. Not only must students of the future learn more, but teachers themselves must be continuously learning to keep their knowledge of their subject matter from becoming obsolete. The capacity of universities to provide an environment in which their teachers can learn will be a benchmark in differentiating the great from the ordinary university of the future. That university which provides its academic staff with time and facilities for scholarship and for relevant basic and applied research will be tomorrow's academic pacemaker.

"Our primary and foremost function will continue to be education--the educating of research scholars, of 'teachers of teachers', and of professional practitioners."

It is the intent of the Urbana-Champaign campus to provide leadership in the effective pursuit of the following objectives:

1. the development of human resources through education

2. the expansion and dissemination of knowledge through research and teaching

1.3 Comments on Educational Guidelines

Our opinion is that the above guidelines are well designed, make sense for the Urbana-Champaign campus, and might very well apply to most educational institutions. We propose to apply them throughout this thesis.

2. ANOTHER INSTRUCTIONAL TOOL

Enter the computer. The promise seems immense. Like books or tutors, computers can serve any goal. They are indifferent to how the processes they apply are created. The man-made programs that control computers can embody universal or particular goals; they can either be mass-produced or hand-tailored on the spot. Like a book, a computer can perform for either a group or a lone individual.

Stored-program technology endows any one computer with great flexability. It is at least as general as a blackboard. Multiple access and communication techniques promise parallelism, that is, simultaneous availability to many students, and also easy physical accessibility. A computer itself is potentially an excellent tool for scheduling anything, including itself. Like good tutors, who can marshal resources beyond their own, computers can marshal most other educational devices and make them perform at their command. Computers have given other devices--slide projectors and tape recorders--renewed dignity as part of the world of technological innovation.

There are many aspects of the educational scene which might benefit from the application of the rules of competition as it operates in the system of free enterprise.

We must encourage as much diversity as possible--as many paths, as many different outlooks, as many different experiments, as many different initiatives as we can afford once the demands of education have been balanced against those of other needs or our society.

2.1 Goals - Individuality

Individuality is a recurrent theme in educational planning. It is responsible for providing:

1. A program of studies that provide a meaningful sequence of subjects for each student according to his abilities, needs, and objectives including a core of common learning for all students that should assure an adequate base of general education

2. Counseling services that will achieve for the student his desire to achieve for himself these merits

Goals of education may be either universal or particular. A universal goal is literacy; and we would like to achieve it in practice. Yet, we do not require that all play the piano. De facto national standards are established by the College Board exam, yet there is no insistence that all pass the exam required of a certified public accountant.

The balance between uniformity and deviation has deep social consequences. How much uniformity does this society need for safety? How much deviation does this society require for progress?

Educational technology cannot be equated with inert devices such as the computer. They are only the kit of tools that people may use in a process to achieve some human end. The kit includes physical devices, "hardware" in the jargon, but it is useless without intellectual content, or "software", which animates the tools and gives them meaning precisely in the way that meaningful printed words differentiate a book from a bound collection of blank pages. The choice of tools appropriate to a purpose and their organization by and with people into a harmoneous, well-balanced process that fits the stated purpose is an important part of the job of systems designers. Defining the purpose is

policy making and not systems' design, although in practice means and ends are never independent of one another.

2.2 Cost Versus Value - Goal Dependent

I feel it is necessary to clarify the cost verses value issue. Cost is the more easily defined, for purchase or rental of equipment is a true cost. It may be presented more complexly, however, if the direct expenses are amortized, presented, or hidden in many other ways depending on the methods of accounting.

Value is goal dependent. The extremes are: to consider on the one hand only dollar values, such as teachers' salaries or pupils' equipment and/or lifetime earnings, or on the other hand, to always place human values and the human spirit over system efficiency. Let us review some factors that, though not logically independent of one another, are sufficiently distinct to be considered in isolation. Flexibility or adaptability is the ability of man, machine, or organization to meet the needs of the moment. People have varying degrees of flexibility. Organizations that encourage individual initiative are more flexible than those that work solely by the book. Brick walls, folding partitions, screens, and movable furniture are increasingly flexible ways of partitioning a room. The value of each depends upon whether changes need to be made in years, hours, minutes, or seconds. The choice of course also depends on cost, fire retardation, noise resistance, etc. Now a blank piece of paper and a chalkboard can both be written on; what is written on one can be written on the other. They possess great generality for most anything can be written on either. Since the board can be more readily erased by the line, word, or letter, and have a ready insertion, it is more flexible.

Parallelism is the simultaneous availability of multiple instances of a given resource. Because a roomful of students during an exam writing on his own paper is common, paper is more parallel as a resource than the chalkboard which will accommodate only four or five pupils. The amount of a resource, say a ream of paper, which could be easily distributed, or a "flexible" stenographer's pad used only by the secretary, is important, as is physical accessibility.

The ease of getting at a resource usually depends on two barriers: the distant supply room--a physical restraint--and management inventory control where "X units will be available for the month of April". Organizations' audio-visuals are usually stored remotely to normal user location. Obviously, parallelism is low. If there are many calls (demand) for device Q, scheduling may develop into a serious problem.

2.3 Maintenance Preparation - Reliability

Reliability and maintenance are as hand-in-glove. Light bulbs burn out and need to be replaced. The bulb is "expected" to burn (reliable) for twenty-five hours in a certain projector. The machine will be returned for maintenance--a five minute bulb replacing project--one day after it burns out. The machine will be in the shop two days. Highly reliable bulbs might signal a 24-1/4 hour-use shop rotational scheduling time sequence to the Department of Maintenance, etc. Low reliability might bring a "bulb replacement class" so that an extra bulb with the machine might easily be replaced. Preventive maintenance may be the running of a fan an extra five minutes so that the filament cools to room temperature.

With the shift from the large to the smaller user, or if you will, from the device costing $1,000.00/month rental down to $100.00/month, if budgeted service expenditures are to remain at a fixed percentage of the monthly-rental, the lower device must be ten times more reliable and ten times easier to service (if ease and time of service can be directly related). Points to consider include the number of moving parts, the total life cost, the number of wear points, and the mean time to repair. Modularity expresses itself in ease of serviceability and maintainability.

A non-pursued point: The consultants would be competent to trouble-shoot outages, etc. Repair teams would be hired on a competitive basis from within the organization (University of Illinois student/faculty community).

Device complexity affects training, operational use, and maintenance. A chord organ is easier to learn to use--less hours of training are required before playing for your enjoyment than the pipe or electronic theater organs. Maintenance of the chord would be equivalent with the electronic theater organ while maintenance crews for the pipe organ requires extensive training.

People should feel at ease and comfortable with whatever device they are using. Not only does the operator desire the physical plant to fill this need but also he wants to "feel" the assurance of what he considers the proper response to his prepared stimuli. Clearly this is closely tied with reliability.

The standard 820 roll of film is useless to one with a 35MM camera. The most impressive investment in programs tailored specifically to one computer is worthless to the owner of another computer if that machine uses a different "language". Now then, this stains of integration, the ability of two media to work together. There is no system if, when given a textbook outlining

experiments, there is none of the required equipment in the laboratory. A book with blank pages--it contains nothing--cannot be a textbook; similarly, a computer without programs is impressive but is equally worthless.

3. JUSTIFICATION FOR THE USE OF COMPUTERS

Having considered many computer descriptors, let us see if, given the technology, there is demand enough to justify its use. John R. Pierce, Executive Director of Research, Communications Science Division, Bell Telephone Laboratory, in the keynote address before the "Conference on Academic and Related Research Programs in Computer Science" held at the State University of New York at Stony Brook, June 5-8, 1967, draws this conclusion as Chairman of a President's Science Advisory Committee (1966):

> "About 35% of all college undergraduates were in courses of study in which they could make substantial use of computers; i.e., in many of their courses computers could help. About 40% were in courses of study in which they should make use of the computer; i.e., they would make use of computers in several of their courses but not the majority. The remaining 25% were in courses in which they should be exposed to the computer and use it in one or more courses. THIS MEANS THAT EVERYONE, IN UNDERGRADUATE EDUCATION SHOULD HAVE SOME EXPOSURE TO THE COMPUTER AND A LARGE NUMBER OF STUDENTS SHOULD USE IT EXTENSIVELY." (emphasis mine).

Under the assumption that computers are useful devices, which do something for somebody, it is worth thinking and talking about the objectives of a computer science education.

1. train effective workers who will be included in the force of some hundreds of thousands of professional programmers and system analysts who will be using digital computers

2. train computer designers or "system architects"

3. train people who will have extensive knowledge of computers and those mathematical tools required to develop new ways of using the computer. Equip them to recognize and to realize new and important applications

4. train a select few in more theoretical aspects of computer science and other relevant subjects so that by their research they can further our understanding of effective procedures and the kind of mental processes that can be accomplished by them

3.1 Problems Requiring a Solution

Needs fall into three (3) categories:

1. personnel required by business, government, etc.

2. solutions to known problems such as how to devise a reliable computer billing system or a reliable computer operating system

3. formulation and solution of such vague and little understood problems as how to control computing systems and make them most effective to extend human intellect and human freedom

To fill these needs, it is clear that three different type objective courses are required: tool courses, liberal arts courses (including computer appreciation courses), and the professional level computer science courses. Further, the primary responsibility of the computer science faculty is an intellectural one rather than a material or service responsibility; i.e., the primary responsibility of the computer science department is education and the primary duty of the computer center is service.

To be even more definitive, there are three types of users: novice, technician, and programmer. A novice user creates no programs--he simply supplies parameters to programs produced by others. Clerks, secretaries, foremen, librarians, teachers, and managers qualify as novices. Using the system on an interactive level, the notice programmer is restricted to functions such as data entry, inquiry display, report generation, and function invocation. The technician is a specialist in the intricate details of an occupation such as engineering, finance, marketing, or manufacturing. He is a professional, but not in programming. The programs he writes will solve his own problems or those of a novice, although he is not aware of the system's hardware features or capabilities. The kinds of functions used by the technician include file and data-base definition, data entry, procedure definition, editing, and simple program debugging.

Professional programmers use PL/1, FORTRAN, assembly language, etc. These users produce programs to meet the computational and data processing needs of an organization. To accommodate their needs, the system provides facilities to define hierarchies of named files; enter programs, data, and text into files; translate source programs to form executable codes; test the resulting objective programs, and insert them into the system to form new commands and programming facilities.

This would not be complete if I neglect the definition of computer science. "The study of computers is computer science," is a simple answer. It is not quite so easy to answer some of the objections. These will be brushed aside however in favor of two quotes on the subject:

> PERLIS: Computer Science is the study of the design, analysis, representation, and application of algorithms on computers. All aspects of this study are like the layering of the onion. The study of algorithms is through the use of algorithms, and each reveals others to study. Computer Science has one goal: the understanding of the organization and administration of information.

> SLAMECKA: Let us suggest that "information" or, more precisely, signals (signs) and symbols be considered as the denominator of our field ... Information is the one component which occurs in the problem, in the solution algorithm. The entire process of converting a problem, from the first recognition of its existence to its acceptable solution, can be viewed as a process of sign or symbol manipulation.

3.2 Needs of the System Fulfilled

Although the number of computers in use in the University has increased tremendously, the Rosser Report points out that the value of equipment installed in universities remain between four and five percent of the value of equipment installed in the whole country. The basic purpose of a university is to develop

and to transfer knowledge. Eduction is an extracting process, a talent-developing exertion. Eduction is a stimulative effort attempting to maximize enlightenment from its sources wherever and whatever they may be. An eductor cannot see what has not hove into his view BUT he is aware of the unknown or he would not continue to reach for the sun. To the self-responsible: let the reliance be solely on eduction; i.e., leave it to each person to turn his eye to any or whatever light(s) he chooses. Permit him to be his own eductor; to educe, drink in, infer from available data, as he pleases.

A major ingredient of knowledge is information, and therefore, one would expect logically that the use of a computer should grow at a fast rate. It is assumed that the growth in the use of computers is limited primarily by the rate at which knowledge about computers diffuses both to specialists (those who know how to make the computer produce output) and to non-specialists (those who use the output of the computer). If this conjecture is true, it follows from the statistical data of the Rossier Report that the effective diffusion rate of relevant knowledge is no greater in the university than it is in the rest of the country.

It is worthwhile to emphasize that activities and decisions related to computers are important to universities for at least two major reasons. The university has a responsibility to provide the opportunity for the type of atmosphere people need for successful careers in our society. With the increasing number of computers installed, more people who are knowledgeable about computers are needed. This includes not only education of specialists such as programmers and computer scientists, but also education for those who will use the computer as a tool. Secondly, with the ever increasing expenditures on education, there

is an increasing emphasis on efficient use of resources and the computer can be a powerful tool for more efficient use of resources. The 1971-2 expenditures are estimated at $414,000,000--up from $100,000,000 in 1968-9; less than $25,000,000 was spent in 1965. If all of this money had been spent for computer service on an IBM 7094-II at a cost of $300/hour of processing, about one minute of computing was available for each undergraduate for the entire year. Or, if you will about 5% of the students could have received about twenty minutes of processing per year.

Expenditures on computers are reaching significant size, becoming increasingly more visible and will likely increase at a faster rate than other expenditures. More on this matter will be discussed later. A point to ponder: the cost of providing "adequate" computer systems is estimated at $60 per student. This compares to the $50-$200 per student for college libraries and $90 per chemistry student per year for a single chemistry laboratory course in a four-year college.

Having expended a sum of money so as to have sufficient hardware capability of the right kind available, effective use is now proving to be difficult. The basic problem is in the paradoxical life cycle of a particular computer configuration at an installational. When the computer is first acquired it is not fully utilized because not enough problems are programmed for it. The quality of the service to the user, "turnaround time", is good and the amount of use increases rapidly as problems are programed and users become aware of the service. As the computer nears saturation, "turnaround time" becomes worse. By adding hardware components and by increasing the hours of operation the director of the service center can prolong the user's tolerable turnaround time after which the user will either seek other sources of computing or forget about it. Now comes the next generation computer on the market and the cycle is repeated

when it arrives.

A final point, the Mitre Corporation project costs for 1974 corresponds to 5% increase in today's education costs--an increase that could be offset by adding only one student to an average class.

4. INSTRUCTIONAL USE

As has been noted, in the field of scholarship and education, there is hardly an area that is not now using digital computing. In the words of the Pierce Report on Computers in Higher Education, "Computing increases the quality and scope of education." In the book, INFORMATION, published by Scientific American:

> "The primary movement in contemporary applied science is the assumption by machines of functions that until now could be carried out only by human nervous systems. The mechanization of functions that are too fast, too dangerous, or too complicated and time consuming for control by man, or that are unworthy of human effort when machines can be made to do them, has created a whole new technology--the technology of information."

Describing the pervasive effect of computers on our society, the "Pierce Report" reflects:

> "Indeed, it seems that the social and economic gains which can be made through the use of computers and computing may be limited chiefly by the availability of people who are able to apply these tools in new and useful ways..."

Having noted that "computers and computing are simultaneously an American Resource and a challenge with a lead on the world...which gives as an intellectual as well as an industrial advantage," the report continues:

> "Students in college and universities must see for themselves what a powerful tool computing is, and learn to use it. No matter what his speciality, the student must be given the opportunity of using computers in learning and in doing, and the faculty member must be able to use computers in teaching. Both the individual's opportunities and the progress, well-being, and stature of our society can be increased by adequate computing facilities for our colleges and universities."

4.1 Types of Use

At least three distinct types of instructional uses of the computer lay before us:

1. as a computational and information processing tool for the student
2. as a device for administering instructional materials and for providing feedback to the student as he learns from those material-computer-assisted instructions
3. as a laboratory instrument in the computer science curriculum

The computer enables the student to deal with realistic problems rather than oversimplified models. By lessening the time spent in drudgery of problem solving and in the analysis of data, it frees time for thought and insight. In part, the old is made easier, but more time remains to reach for "new".

If we are to make any meaningful analysis of the uses of computers in higher education, we must mention the types of service. The appropriate unit in discussing computers is a unit of service involving not only hardware time required, but also the programming language available, the specialized hardware which must be attached to the general computer, the response time of the overall facility to that user, etc. The computer facility user is purchasing not machine muscle but a series of accesses to data and results.

As the total demand for computing is rapidly increasing, so also, is the variety of demand for specific services. Thus, facility planning and funding must take into account the consequences mentioned below of providing new types of service. Note how these new service requirements may have severe dislocation effects on the rest of the computer services system.

The incremental costs of providing the first units or a single unit of service generally will be quite high. Lead times may be long due to heavy

software investment required in providing the many new types of service. This together with any specialized hardware involved, the provision of a new service represents an additional large fixed cost whether there are any users or not.

Each facility cannot provide every possible service. Decisions as to which service to provide can imply significant differences both in equipment and in their organization of the facility staff. For some types of service, "stand-alone" equipment dedicated to a single use may be appropriate.

4.2 Centralization Versus Decentralization

This comment on centralization: In any decentralized organization, those able to look across several decentralized units from a centralized location will see people "doing stupid things" - making bad decisions, undertaking activities that duplicated efforts in other units, etc. This is not always because the people are bad or stupid, but more often because they are human, the future cannot be forecast perfectly, and the transfer of information is neither complete nor free. There are two polar reactions to this realization, and an infinite number of "combinations" of the poles:

1. strengthen the decentralized operation (better people, more money, etc.) so that such mistakes become rarer

2. increase centralized direction and control, since the person on top is less likely to make at least some of these mistakes (having more complete information, supposedly)

With this in mind, let us turn to the commonly accepted; "the power of a computer central processing unit goes up as the square of the cost," and thus there are economies of scale in terms of raw computing

power at the CP. It is not always realized that a number of other factors enter into the overall question of economics of scale, particularly when applied to shared use of remote computing resources. Generally, there is no data on a number of these factors, such as economies do not exist for computer memories, and thus no way to make a sound judgement as to whether economies of scale really exist in an actual operational situation or not. Even discussions of the problem are few and far between.

4.3 Computer Utility

The following list of factors which enter into the cost-effectiveness trade-off of a centralized computer facility supplying remote service can be found in the chapter entitled "Economic Considerations" in the book _The Challenge of the Computer Utility_ by Douglas Parkhill. While his discussion is mainly oriented toward remote time-shared service, most of the factors apply. The possible positive factors are:

1. fast response (that is, economically feasible fast response)
2. reduced user capital investment
3. better utilization of computer power (the blending of disparate peak loads at different times)
4. better balance between user needs and user costs (since there are a number of users possibly using different parts of the system at once)
5. greater computer power for the user (a larger single machine available when needed)
6. convenient access to broader set of data procedures
7. flexible system augmentation and modernization
8. reduced user maintenance and operating costs

Negative factors listed include:

1. cost of communication facilities - this would include both remote lines and the terminals needed at the remote facilities

2. executive controller requirements; i.e., the overhead necessary to provide a multiplicity of centralized services)

3. reliability and maintence problems (if the central system goes down, nobody gets anything done)

4. system saturation problems

5. lost time due to "swapping"

A number of economists have pointed out the similarity between computing facilities and the high capital investment, low marginal cost operations of electric utilities. It is a common finding, for such an industry or facility that at a given level of capacity it may not be possible to recover all costs and at the same time use the capacity fully, even though there is demand for the facility's service.

High quality service meaning, for the power company, no severely reduced line voltages or outages and for the computer utility fast turnaround at peak load times, costs money, and shows up as possible unused capacity at non-peak-load times. Sometimes this capacity can be sold to other networks of power companies or computer utilities, or can be used for low priority operations: making aluminum or pumping water up into storage lakes for power companies, or running background programs at reduced rates for some users. The alternative to high quality service, namely partial or total saturation is so wasteful of human time that it is almost never cost-effective if the objective function being optimized includes a factor for wasted human time.

5. COMPUTER AFFECTED PROBLEMS IN EDUCATION

When man discovered how to convert the chemical energy stored in fossil fuels into mechanical power, man's physical capabilities were extended. Today man's mental self has been extended by the utilization of the computer. A logic engine, a symbol manipulator, an information processing machine, and a control device, the digital computer is an invaluable tool in logical problem-solving, and with mechanical equipment, the computer is a flexible and comprehensive task performer.

The responsibility of education extends beyond simply providing appropriate instruction to those who are likely to make direct use of computers; namely, it extends into the introduction of computer concepts as a part of general education. This is in order to provide all students with an understanding of what these devices are, what they can do, and how they are affecting society.

5.1 The Challenge of the Computer

Education is challenged to use the computer as a teaching tool and to reveal how its capabilities have been incorporated in the very organization, structure and content of all current knowledge. Mathematics, engineering and the sciences, while the most obvious, are not the only academic fields directly affected by the computer's capability to process information and to support the development of model systems simulating segments of the environment. Languages studies are affected by techniques of information storage and retrieval and new methods of exploring logical

consistency. Applications to the managerial sciences make business, economics, administration and commerce more viable, comprehensive and intellectually challenging subjects.

The primary problem faced by education consists of determining the relevance of the computer to each academic discipline: how can the computer affect each discipline; develop curricula which incorporates the computer as an integral part of their subject matter.

Another problem is developing operational methods which will facilitate maximum ease of computer use at educational institutions. This includes the development of computer languages geared to fast learning and easy programming and the design of classroom facilities, course schedules, and terminal devices for optimum computer access.

The final problem lies in providing computer services to classrooms on a cost effective basis which will make computer-based curricula economically feasible for educational institutions of all types and sizes. The question, "Is it feasible?," is not just one of whether a job can be done by a computer, rather, it is one of relative economics and requirements, contrasting various ways of doing it (including improved non-machine methods.) Quoting Dr. Peter G. Lykos, Computers In Education:

> "There are two basic ways in which the computer can be used. One consists of computer-assisted instruction in which the student sits at a terminal and responds to programmed course material. This requires that the pedagogical technology be sufficiently advanced, that "success" and "failure" are adequately adapted to each student and that the concepts sequence for the subject matter be optimally organized. It also requires that the computer and computer terminal hardware and software be sufficiently well developed and economically feasible to support mass education.

> The second method involves the student addressing the terminal as a stand-alone device in one of two distinct modes of operation. In one operational mode, the student confronts a problem, writes a program to work through a solution to the problem, and then uses the computer to implement the solution. In this case, the student works out the solution himself and the computer is simply a tool enabling him to solve the problem. (If you will, the student is the teacher - the computer the pupil).
>
> In the second mode, the computer contains an application program and the student uses this program to solve a problem. The program may simulate the economy while students play the part of individual companies attempting to maximize their profits. This second mode has great potential today, but has not been exploited (or recognized?). It constitutes a direct channel between the frontiers of knowledge and the classroom..."

We suggest yet another way in which a student who is required to use the computer benefits educationally. In his career he uses a number of different computer languages, both low level and high. Many students use four or five different ones, and some use well over twenty in their college careers. Each language represents a different way of organizing data and approaching problems. Just as travel is said to be broadening, and it is, so with computer languages.

The computer touches everyone's life in a direct or indirect way. The educated man of today must therefore be fully aware of the challenge and problems posed by the computer. It is consequently one of the objectives to establish guidelines to make computer-in-education an economically feasible, technically viable, and academically effective reality. Achievement of this goal is essential for man to realize his full intellectual capability.

5.2 <u>Growth Impeded?</u>

In the MINUTES OF MEETING COMPUTER NETWORKS ADVISORY COMMITTEE, June 15, 1970, STATE OF ILLINOIS BOARD OF HIGHER EDUCATION, Dr. Lykos points to a number of problems impeding the growth of academic uses of the computer:

1. the main problem lies in discovering how computers can be used as an integral part of curriculum

2. the developing computer languages geared to fast learning and easy programming

3. the providing of economical services to eductional institutions so that we can afford to use this tool

Dr. John Kemeny of Dartmouth states:

> "At Dartmouth 80% of the freshman classes will have completed four significant exercises, in which they personally "debug" their own programs by the end of their year. A significant number of students acquire the habit of regular use."

Before introducing another quote of Dr. Kemeny, it should be clear that at Dartmouth, they believe that learning to use a computer should be an essential part of a liberal education. The average graduate is almost sure to need a computer in his work within this decade. Certainly they avail the student the opportunity to use this powerful tool. Now Dr. Kemeny:

> "After placing the computer at the fingertips of the faculty, not only does the instructor use the computer but also he feels free to ask his students to work significant exercises and term projects on the computer. He may be sure that his students know how to use a computer, that they will be available, and that the student will enjoy the assignment."

There are two probable reasons for their success:

1. an easy-to-use timesharing system

2. a simple language

For the few readers requiring more background to the foregoing, let it be said that batch-processing was designed to maximize the use of the computer for a large number of significant problems--which are known to be correctly programmed. But since man is not infallible, after waiting several hours to obtain the results, probably with mistakes, the user must then make a correction, and resubmit the problem. It may take two weeks of rather frustrating work until the programmer succeeds. Yes, computer time may be optimized but not man's. To handle many users with one machine, the time-sharing system was discovered.

Most programmers have had moments of deep discouragement as they drilled into their minds another language. The aim of producers of the language was time: the language should be so simple as to be learned in two or three one-hour meetings. After the initial meetings, the student would learn from their own experience. (A language like FORTRAN or SNOBOL requires that the user remember a large number of conventions and that he specify a wide variety of options. This is too much. It is harder to learn the language and the occasional users have to "relearn" the language each time.) The language should encourage the novice; i.e., he should be able to do something interesting on the computer during the first week of the training periods.

5.3 A Testimony of Success

At Dartmouth, all freshmen who complete a year of math are required to complete the freshman computer program. After the initial introduction, each student has a teletype reserved for him for 3/4 of an

hour per week, for nine weeks. He must write four assigned programs, debug them, and pass the computer TEST on each program. "Experience shows that students spend between one and two hours a week on their programs including teletype time, and that 95% of the programs are successfully completed."

Experience at Dartmouth indicates that the students find it convenient to use the computer for their homework and term assignments. They use the computer to solve course problems without being told that they should do so. (Students naturally try to find the easy way.) Dr. Kemeny notes that the upper classman is often working two or three digital programs per week as part of his regular course work.

After a language has been mastered to the extent of being a basic tool - that is, the student has no particular difficulty (clerical errors aside) in coding a problem which somebody else has analyzed, formatted and flow charted, he is ready for the next stage in the learning process, namely problem formulation. This is more difficult to do, more difficult to teach, and is not taught often enough now. If the student succeeds in developing this ability, he is ready to address himself to very difficult problems over those he did not understand when he first attacked them.

6. STRUCTURE AND CONTROL OF THE COMPUTER FACILITIES

When is computer decentralization justified? "When one division of the university may use so large a fraction of the resource - perhaps as little as 5%," says Calvin C. Gotlieb, University of Toronto. We suggest a more pragmatic answer to this question; namely, computer decentralization is justified whenever a group has responsibility for regular operation of an essential service.

It is natural for them to want control of the equipment it needs for its work. Soon it becomes undesirable for this group to become completely dependent on a machine which must serve as a teaching and research facility for the university. Inevitably there will be occasions when the group will require pre-emptive authority to have its work run first. It is well known that such occasions do arise when it can be shown that there will be physical hardship to the staff if work is delayed or perhaps when a machine breakdown has resulted in a heavy backlog of work. Jobs for which urgency cannot be demonstrated will be postponed - with the result that teaching and research will often suffer. It may be that a high-priority group will have less incentive to plan for an orderly expansion of facilities to meet its growing needs. The result would be a progressive squeeze on those less able to find funds for their share of the computer costs, or simply with less opportunity to present their cases before the administrators responsible for allocating time. It is just this reasoning which has led many to set up a separate facility for administrative data processing. These arguments also apply to

the rapidly approaching computer utilization in the daily operation of the university library. Computer usages for circulation control, for book ordering, and for maintenance of a periodical file are conventional applications.

6.1 Information Dissemination

Selective dissemination of information, based on matching abstracts against profiles of the interests of users, and the construction of catalogs on disks and tapes are in the pilot project stage. We can soon expect to see indexing, catalog searching, and many other library operations carried out with the aid of the computer. As libraries become increasingly dependent for their everyday functions on computers, we can expect them - in fact encourage them - to acquire their own facilities. It can be expected in the hospitals with which universities are associated for teaching purposes. Obvious daily uses are found in patient admission and billing, maintaining drug inventories, and storage of medical records, supervision of nursing stations, in-patient care, etc.

There are instances in which a computer is required to service or control a single piece of equipment which acts as a major facility for a large number of individuals. A particle accelerator, a bubble chamber, hospital experimental operative units, can justify dedicating, which reflects common parlance among computing individuals and is an indication of a complete allocation of a computer resource to a particular task.

6.2 Separate and Unequal

Reiterating, a separate responsibility is likely to require a separate facility. It can be recognized by the presence of a distinct

organizational structure, with its own staff, budget, space, and facilities, and by the fact that the operation is continuous, and without any time limit set for its duration. The duplication of memory and arithmetic units may be offset in part by the reduction in communication costs otherwise needed for transmission of data and programs to a central facility. The value of advantages of decentralization can outweigh the costs of duplicating some equipment.

Separate but not necessarily equal systems with a general-purpose central facility larger than those dedicated to special functions is recommended based on the belief that a central computer with large capacity memory and high speed CPU, will undoubtedly be useful even to the users of the "separtists.".

6.3 The Central Facility

The central facility should maintain compatibility between the user groups not by name manufacturers but the machines must be able to talk to one another through an established communication link, or by being able to read one another's tapes or disks. It must be realized that this compatibility will add to the cost of one or both of the computers - in extra hardware or in extra programming; and as anyone with experience will testify, it is extremely hard to maintain compatibility between two independent systems, even where there is a strong desire to do so. It will be impossible to do this without setting up a formal mechanism of exchange, and without setting up good documentation of the operational system - a plus value in itself. If these communication channels among different computing groups are established and maintained, the chief inefficiencies resulting from multiple installations will probably be avoided.

6.4 Interface Compatibility

How do you enforce this interface if you allow someone, say the library, to install its own computer? Furthermore, presuming that this problem can be solved, so that you have the interface, you no longer have separate communications, indeed, you have a network. As to the interface, an advisory committee should consider, in every case whether interfaces and communication channels are provided and whether they are adequate and not too expensive. A computer with limited I/O equipment must include a budget for such interface items as data phones. Sometimes there are alternatives to data phones. An example from the University of Toronto: there physicists were considering a PDP-8 for their linear accelerator. Now even though it was to be a stand-alone facility, they installed a tape unit, with tapes which could be read by their IBM 7094. They had to buy an extra piece of equipment to assure compatible tapes. This was worthwhile for not long after, they were logging data which is processed on the 7094. This compatibility is not of people and programs. Compatibility is taking the form of conversion, e.g., data conversions. Note how important it is to have a good information distribution system.

7. THE COMPUTER AS AN EDUCATIONAL TOOL

Now let us concern ourselves with those educational applications of the computer in which the student, not a teacher or staff member is interacting with the computer. Briefly, the computer can be used five ways:

1. Under the control of a previously prepared program, the computer can exercise the student in skills--just as a drill master.

2. Under the control of a prepared program the computer will perform the tedious calculations to expedite the student's progress through various course work--a programmed desk calculator.

3. Under the control of a previously prepared program, the computer will simulate in the classroom real world situations, theoretical or abstract models--a simulator.

4. Under the control of a previously prepared program, the computer will engage the student in a question-and-answer dialogue designated to aid him in the formation of concepts--a tutor.

5. Not under the control of a previously prepared program, the computer may serve as a sophisticated tool to be programmed by the student as an aid in algorithmic thinking--a problem solver.

The computer will be a fact of the student's life in years to come. The contact he initiates in this program will continue into his later life. The importance of on-line use of the computer is because it teaches algorithmic thinking. With falling costs, the computer can find its most important application as a medium for individual instruction. The advantage of graphics terminals for certain types of problems is very clear. It is also true, although people who have only had experience with batch processing are unaware of this, that program debugging is perhaps twice as fast if done from a console, even as imperfect a one as a teletype. This is so because of powerful existing facilities operating on user files and the ability to initiate a large number of

runs in a short period of time. In this mode it gives the student prompt feedback or knowledge of his results. It adapts the content of instruction and the techniques of instruction to the student's individual requirements as revealed by his interaction with the computer.

7.1 The Teacher's Responsibility

A teacher's most important goal is to arm the student with all the necessary tools for self-learning. An appreciation for books, a motivation to study, a desire to know, an acquisition of curiosity, and yes, the computer.

In structuring a course, a teacher asks the following:

1. What specifically is to be learned?
2. How must one design achievement measures?
3. Can the course objectives be communicated to the students?
4. What acceptable proof is there that the course objectives have been met?

In a question-answer series (tutorial) between student and computer, wrong answers are followed by remedial explanation. Computer quiz indicates a series of questions initiated by the computer and answered by the student without remedial explanation. The student score is automatically recorded for the teacher's records. Computer learning refers to the situation of a student programming a problem for the computer in such a manner as to give greater insight into the problem and subject matter. Computer simulation indicates a program which causes the computer to mimic physical phenomena and to graphically display the results. This allows the student to study the nature of a situation and analyze the consequences of several actions before approaching the actual physical problem. Less time is spent in the drudgery of physical experimentation.

7.2 The Student Stimulated

A lack of a mathematical aptitude or inclination often makes the physics course, for example, a discouraging experience. Interesting and vital concepts of physics need not be lost for one may use the computer to assist students with varying mathematical abilities to understand and retain both the mathematical manipulations and the concepts of physics. Most early mathematicians, I note, did a tremendous amount of numerical experimentation. Gauss was a supreme example of this. They found facts, relations and patterns before they decided what was true and tried to prove it. Likewise, many students don't really appreciate what the facts are because they learn formulas but don't get to look at numbers or graphs.

Note the normally written equation forms of the man-made axioms of natural phenomena found in problem-oriented courses (mathematical or logic in contrast to biology, or business in contrast to history). Use of the computer in these problem-oriented courses removes the idealizing assumptions: no longer is the closed-form analytical solution required. One might let the computer output drive an oscilloscope so that the student's solution becomes immediately visible. Many problems have been given the student, that by necessity, assumptions are made which are known to differ from the actual physical phenomenon being studied. The computer's speed allows the consideration of "non-idealized" situations. While the consideration of air resistance or changing force of gravity is beyond the scope of most elementary physics textbooks, with the computer even the non-science students can be made to realize the effects of numerous real parameters on the solution of existing problems.

Consider courses where no computer language is required; i.e., the student learns to operate the computer terminal and necessary instructional information is prepared (preprogrammed by the teacher). This method is well suited for those requiring considerable amounts of drill and training--repetitive exposure, and memorization. Electrical engineering students must be trained to operate the oscilloscopes for signal measurement and detection. The computer is used to lead the student through a series of training steps followed by questions to probe the student's understanding. Progression comes after mastering previous steps. While most courses require some drill and training, some courses seem to require more than others, for instance: languages more than mathematics, medicine more than economics, and chemistry more than engineering. Subject matter for drill and training is presented in question and answer form very similar to the programmed textbook. The computer has the advantage of flexible presentation of the next learning frame, and continual record keeping of the student responses. The computer terminal can display pictures and graphs, or can be made to access a slide-projector cartridge. The obvious advantage of the computer for drill and training is that the student is self-paced and continually informed of any deficiencies in retention of subject matter.

7.3 Programmed Course Work

"The only way to learn a subject is to teach a subject" is often heard (and true!). The student needs to take a more active role in the learning process and to set the pace in relation to his own limitations. The teacher of a course would present the student with a list of objectives which he must master before the teacher will be convinced that the student has fulfilled his responsibilities of "knowing" the subject. The physics student may be told at the completion of a

certain segment of the course, he must be able to:

1. Derive Maxwell's equations.

2. Demonstrate Conservation of Energy.

3. Plot distance as a function of time.

By letting the computer manage the student response data the teacher can immediately see when and how often each student has used the computer; and, there is a record of all correct and incorrect responses making it possible for the teacher to pinpoint difficulties in student understanding and insuring prompt remedial action. The student need not "guess" what the teacher requires of him or what the teacher thinks is important, for realistic course objectives are monitored by the computer. The student may be given the following objectives:

1. Determine the motion of a mass-spring system when acted upon by a force.

2. Write a computer program to determine the position of the mass at any time.

3. Prepare a computer program to plot the results of part 2, above.

A statistics course taught with the aid of a computer is exciting. No longer do coins or dice have to be tossed 10,000 times; using the random number generator enables samples of this size to be simulated in seconds. Using available algorithms students can plot the sampling distributions and can approximate the statistical tables. (Statistics--Traditional and Bayesian, Victor E. McGee, Appleton-Century-Crofts, 1968).

The computer is employed to assist the teaching of an optics lab where exact calculations are tedious and uninteresting. Students also turn to the computer as a matter of course in order to carry out such tasks as experimental curve-fitting, solution of differential equations and other numerical integrations. Monte Carlo calculations, and routine arithmetic manipulations

formerly consigned to the desk calculator. Graduate students find it a vital research tool, as do some faculty members, who also depend on it to process grade in the high-enrollment courses.

What about a lab organized around the computer in a way that the physical phenomena of mechanics might be displayed in tight conjunction with the math models intended to describe them. The student would be permitted to "play" with the parameters of the theory, much in the same way that he plays with experimental parameters in a conventional laboratory.

7.4 The Team: Student-Teacher-Machine

It is not a question of man versus the computers but the tasks should be done by man-machine teams. Suppose we are given a problem involving millions of computations. The programmer must foresee everything that could possibly happen during the logical chain, and provide for it in his program. Human beings are not very good at doing this. Or, if they succeed, the price is tremendously complex programs that must provide for all kinds of catastrophes, most of which never occur. By letting the machine do a reasonable piece of the work and then report the results to the programmer, he can then use his judgement as to whether to proceed, or to change the plan of operation. It is thus not necessary to program human common sense; it can be applied by the human being when needed.

The point is, learn how to work with the computer in solving a problem, rather than submitting a problem for machine solution. It is the student "teaching" the computer. By being able to program certain processes, the student necessarily shows a thorough understanding of the process. Writing a program to add fractions shows a complete understanding of the process. To develop the manual skill for performing such calculations, the computer can be easily used to drill the student.

The computer has the additional advantage of encouraging the student to admit that he has not learned or understood a particular concept. In contrast, all teachers have experienced the natural reluctance of students to ask questions in class for fear of exposing their culpable ignorance of the subject matter. The computer presents a problem to the student and waits for the response. Depending on the user's response, the program will give the student a hint, show him how to work the problem, or give him another problem. In this way, the tutorial session is tailored to meet the individual student's needs.

Rather than just listening in class, the student is encouraged to take notes (pencil and paper become tools for learning). This same student reads about the thoughts of others in books (learning tools) and he may use problem workbooks or programmed textbooks. The student has also been taught to make use of libraries and film to further his understanding of subject matter. The digital computer now poses the question of combining the advantages of existing eductional tools with those new tools and concepts derived from computer technology. How to stimulate and guide students into this active role of acquiring the skill to search and organize a field of study essentially augmenting their abilities by means of a computer presents a real challenge to teachers everywhere. Repeating, the student must be guided to explore concepts with the computer which were impossible or impractical by normal classroom techniques.

7.5 <u>The Student/Teacher's Records Keeper</u>

With the computer designed to store and retrieve vast amounts of data, it is not surprising that we consider its role as academic records keeper. If one considers homework, laboratory and daily class work, plus examinations, a student can easily generate fifty items of data in a semester. Fifty data points times about as many students could reduce the teachers role to that of a full-time

record keeper. The teacher may require the computer to compare the current class with previous classes and in this manner have an indication of whether to spend more or less time on certain subject matter. The computer would thus relieve the teacher of much tedious record keeping and allow more time for direct interaction with the students both as a group and as individuals. The computer becomes a management and decision-making tool for the teacher, constantly informing him of the progress and differences of each individual student.

The computer has the capability to store in its memory the complete picture of a student's abilities, aptitudes and desires, and to compare these with the professional requirements of numerous careers, thus making it an informal student counselor.

The calculations made by the computer are so rapid that individual points and line segments can be continuously displayed on a CRT. CRT results can be filmed and shown to groups or classes of students; e.g., in a physics class dealing with vectors, one might imagine describing the addition of vector quantities by a computer-generated display of a continuous sum of two rotation vectors. In chemistry, the symmetry of molecules can be studied by a computer model relating such parameters as bond angle, bond length, and atom location. For the teacher of engineering, drawings will find considerable application of the three-dimensional computer display of design objects. These objects can be rotated and inspected from several views on a graphic computer terminal. Consider writing the script, producing and directing a computer animated solution to this: the production of a square wave using Fourier terms needed for the solution. This animated version of a normally complicated problem lends much interest to the classroom demonstration.

A final example may be found in the natural language conversation between man and computer: the ELIZA program developed at MIT under Project MAC. The computer is programmed to analyze input sentences on the basis of "decomposition rules" which are triggered by key words appearing in the input text. Responses are generated in reverse, that is, "reassembly rules" associated with selected "decomposition rules". The choice of the key word in the input statement is important. For example, in the line, "Men are all alike", 'alike' is chosen as the key, and a routine response returns, "in what way".

In conclusion, a computer-integrated course exposes the student to computer techniques within the framework of the normal course. An undergraduate physics course would enable science students to acquire computer skills by solving physics problems on the computer during the semester. Non-science students, many of whom will later be in decision-making roles in industry and government, must also be exposed to computing and its practice, its powers, and its limitations. The type of exposure to the computer depends upon the subject matter, and the type of student participation planned. The selection of a computer system and its utilization falls within two broad categories, each of which is dependent upon the kind and amount of student involvement:

1. The student programs on the computer an assigned problem and obtains his own solutions.

2. The student changes the data parameters of an existing program and learns through analysis of the computer-generated results.

8. THE MINICOMPUTER

As noted, it is one thing to teach a student to use a computer while it is an entirely different problem when considering the use of the computer to teach the pupil (or even considering the pupil "teaching" the computer). Yet, in any case, to attain these goals the computer facility must be readily available; the physical plant and the media of student-machine communication.

Having passed through the three major communication media cycles: verbal--the communicator and his audience were in direct contact; literal--information transmitted word/sound by word/sound; optical--a picture is worth a thousand words; we are now in the "age" of electronics. We can utilize all three media in reinforcement of each other and, furthermore, implimented by the tactile element of muscular learning as the man and machine interface (interact).

Consider now an addition to the educational environment: the "computer laboratory". This laboratory would be a room dedicated to a computer service. It would include instructional materials as supplied by the faculty, "reserved" textbooks, and possibly, high demand periodicals. A consultant would be available at all times; there would be a consultant for each "laboratory".

The remainder of this paper will be a discussion on how this "laboratory" can provide fast, turn-around performance for the minimum cost. First, turn to Table #1. This table is entered as an indicator of the "high" cost of computation. This table gives the number of operations

possible for one dollar ($1.00). It includes the medium-to-large machines that give the most operations for the common cost; those missing will not give you as many operations for your money.

TABLE 1

Cost/Performance Standardized to the 1970 Edition,
Auerbach Computer Characteristics Digest

SYSTEM	IDENTIFICATION	CONFIGURATION STANDARD	OPERATIONS/$1.00
BURROUGHS	B5500	III	1.2374 x 10 6
	B5500	VIIA	.9318 x 10E 6
	B6500	VIIIA	1.5 x 10E 7
CDC	3100	VI	3.4595 x 10E 6
	3100	VIIA	2.4806 x 10E 6
	3300	VI	5.412 x 10E 6
	3300	VIIA	3.991 x 10E 6
	3400	VI	9.346 x 10E 6
	3400	VIIIB	3.983 x 10E 6
	3600	VIB	5.930 x 10E 6
	3600	VIIB	5.848 x 10E 6
	3600	VIIIB	4.169 x 10E 6
	6400	VIIA	8.731 x 10E 6
	6400	VIIIA	6.739 x 10E 6
	6600	VIIA	4.505 x 10E 7
	6600	VIIIA	3.769 x 10E 7
G.E.	215	I	2.0583 x 10E 5
	215	VI	1.5178 x 10E 5
	225	VI	1.8575 x 10E 5
	235	VI	1.2155 x 10E 6
	415	VIIA	1.5602 x 10E 6
	425	VIIA	2.0366 x 10E 6
	435	VIIA	.2249 x 10E 7
	635	VIIA	.4739 x 10E 7
HONEYWELL	1200	VI	1.6004 x 10E 6
	1200	VIIA	1.0855 x 10E 6
	2200	VIIB	1.3449 x 10E 6
	3200	VIIB	1.4022 x 10E 6
	4200	VIIB	1.6729 x 10E 6
	8200	VIIA	.8612 x 10E 7
	400	II	.6637 x 10E 5
	400	III	.5155 x 10E 5
	1400	II	.4266 x 10E 5
	1400	III	.3870 x 10E 5
	1400	VI	1.3914 x 10E 5
	800	VI	1.1700 x 10E 6
	800	VIIB	.8353 x 10E 6
	1800	VI	.2035 x 10E 7
	1800	VIIA	.1653 x 10E 7
	1800	VIIIB	.1093 x 10E 7

TABLE 1 (continued)

SYSTEM	IDENTIFICATION	CONFIGURATION STANDARD	OPERATIONS/$1.00
IBM	360/25	I	.6965 x 10E 6
		III	.3887 x 10E 6
		IVR	.2563 x 10E 6
	360/30	I	.8473 x 10E 6
		III	.4999 x 10E 6
	360/40	II	1.4802 x 10E 6
		III	1.3018 x 10E 6
		VI	.9212 x 10E 6
	360/44	VIIA	2.8688 x 10E 6
		XI	4.288 x 10E 6
	360/50	III	.3866 x 10E 7
		VIIA	.3020 x 10E 7
		VIIB	.2727 x 10E 7
	360/65	VIIB	.9902 x 10E 7
	360/75	VIIB	.977 x 10E 7
		VIIIB	.721 x 10E 7
	360/85	VIIIB	1.267 x 10E 7
	360/165		2-6
	7010	III	.6243 x 10E 5
	7010	VIIB	.4864 x 10E 5
	7040	VIIA	1.5354 x 10E 6
	7044	VIIA	.1670 x 10E 7
	7074	VIIB	.6116 x 10E 6
	7090	VIIB	.1010 x 10E 7
	7094-I	VIIB	.2102 x 10E 7
NCR CENTURY	100	IIIC	1.315 x 10E 5
	200	IIIC	1.203 x 10E 7
RCA	70/35	I	1.066 x 10E 6
	70/45	III	.1547 x 10E 7
		VIIB	.8350 x 10E 6
	70/55	III	.3652 x 10E 7
		VIIB	.14876x 10E 7
	70/60	III	.3062 x 10E 7
		VIIIB	.1399 x 10E 7
	301	I	.4734 x 10E 5
		VI	3.1394 x 10E 5
	3301	VI	.7086 x 10E 7
	3301	VIIB	.4679 x 10E 7
UNIVAC	III	III	1.520 x 10E 5
	490	VIIA	1.293 x 10E 5
	491/492	III	.3537 x 10E 6
		VIA	.2015 x 10E 6
	494	III	.2506 x 10E 7
		VIIA	.2052 x 10E 7
	1106	VIIA	1.787 x 10E 7
	1106	VIIIA	1.099 x 10E 7
	1108	VIIA	1.545 x 10E 7
	1108	VIIIA	1.114 x 10E 7

TABLE 1 (continued)

SYSTEM	IDENTIFICATION	CONFIGURATION STANDARD	OPERATIONS/$1.00
ILLIAC IV			60 x 10E 7 Est.
PDP 10			3 x 10E 7 Est.
PDP 11			25 x 10E 7 Est.

8.1 The Cost/Performance Ratio: Reduced

Enter the Minicomputer--the cheapest form of digital logic system that you can buy today! Is not this the answer to the question, "Why is it that many of the tasks once handled by the hardwired logic system or by the large, expensive computers are now being done by these small, programmable digital computers?"

When acquiring a computer, one can expect to incur costs in these areas: acquisition, space, supplies, and maintenance. Housing a computer may also create problems of space, power, and air-conditioning. Fortunately, such requirements are virtually non-existent among the new minicomputers. Most may be housed in a well-ventilated closet, if necessary. They require no special air-conditioning and run on standard 110-volt, 60 cycle power.

The annual cost of a maintenance contract will average one percent of the total purchase price on purely electronic equipment, and 4.5 to 6 percent on electromechanical units. In general, the purely electronic equipment, such as a central processor, is far less expensive per unit of processing power (and much more reliable) than are electromechanical units such as card readers, printers, and teletype-writers.

Note that a computer is most economical when (1) the work load in the system is sufficient to utilize the equipment fully; and (2)it will not be necessary to get rid of the equipment after a year or so. This is an important point when considering the minicomputer.

The following few sets of statements might be useful, when, in

the decision-making procedure, a computer is to be chosen:

1. What are the applications to which the computer will be applied?

2. The applications require what from the computer system: requirements of language, input/output, storage, throughput responsiveness

3. Select the computer service which offers the utilization techniques required and best meets other application requirements.

4. What type of computer utilization offers the throughput and responsiveness--time-sharing, batch-processing, etc.?

5. Which vendor can provide this system at the least cost?

But, it is not all that simple.

8.2 <u>The Minicomputer Defined</u>

Before continuing let us get to the starting point: a very basic definition of the minicomputer (certainly there is no consensus of opinion, yet for this paper this will stand); a minicomputer is a small digital computer with word lengths ranging from 8-18 bits. They have around 1-usec-cycle time, 8K word of core (memory) and a Teletype ASR 33 sell for $2,650 - $16,000.00.

A few years ago, no computers were anywhere near this expensive, and the cheaper computers were very slow indeed. Cheap, fast integrated circuits, highly reliable and mass-produced, allowed modest sized computers to be mass-produced remarkably inexpensively. Furthermore, the speed has increased. Racks of the past are now fitted on a few printed circuit boards. With most minis, using a 3-wire, 3D organization with 20-mil cores in a planar array, technology produces in 200 square inches a printed circuit board, 4K 16-bit memory package capable of responding with a 1 micro-second cycle time (and less).

Generally, decimal arithmetic, floating point arithmetic, searches, and byte manipulation instructions are missing from the minicomputer, as are the operations of divide and multiply. While the large machine provide multiple position shifts, many of the minis provide only single position shifts.

Thirdly, by shortening the number of bits stored, transferred and operated on, a definitive characteristic of minis, helps in the cost reduction. If performance, achieved with the short data word length, can be diminished, double precision programming might achieve the required results. The retail price of a computer depends on hardware and software costs. Being a modest little computer, a mini needs a good but not universal programming system. Most manufacturers supply for their machines a basic, a FORTRAN, an assembler, a text editor, a debugging program and a time-sharing system. The total effort required to code up such a system is relatively small, and is charged against a large number of machines. Furthermore, the owners of minis include some very sophisticated computing types who are able to justify and acquire their own computers. Thus, user groups can exchange very good programs.

Cheap as they are, minicomputers may not be the final answer to all problems. Furthermore, we may choose among the minis a more expensive model if the total system becomes sufficiently better.

8.3 Minicomputers--Contrasted and Compared

Many people are misled by the name "Minicomputer" into thinking that they are not fast and not general-purpose computers. In this section, we get down to the details of the computer architecture in order to see that they are well organized, fast, and being of recent design, have more up-to-date features not found in the bigger, older computers. Of course, one should always consider a question: Does the value of the job to be done justify the cost of the system? Note that, at the Spring (1970) Joint Computer Conference, it was reported that sixty-two different manufacturers are presenting to the user nearly one-hundred different minicomputers with a basic price less than $20,000.00. (Bell Telephone Laboratories use one-hundred-twenty minis of which twelve different manufacturers

have supplied thirty-four different models with varying characteristics to satisfy their many specific applicational needs).

Starting with a typical minicomputer, Table 2 contains characteristics on seventeen models from fifteen manufacturers.

TABLE 2

Minicomputer Characteristics

MANUFACTURER	MODEL	PRICE MINIMUM CONFIGURATION	TIME (microsec.) CYCLE	ADD	MULTIPLY
Clary Datacomp Systems, Inc. 404 Juniper Serra Drive San Gabriel, CA	Datacomp 404	$ 8850 (4K)	2	---	98
Compiler Systems, Inc. P. O. Box 366 Ridgefield, CN	CSI-24	$14950 (4K)	.9	1.8	6.6
Computer Automation, Inc. 895 West 16th Street Newport, Beach, CA	216	$ 7990 (4K)	2.66	5.3	42
Data General Corp. Southboro, MA	Supernova	$ 9600 (4K)	.8	.8	3.8
Digital Equipment Corp. 146 Main Street Maynard, MA	PDP-11	$10800 (4K)	1.2	2.3	4.5
Digital Scientific Corp. 22455 Sorrento Valley Road San Diego, CA	META4	$15650 (4K)	.9	1.8	5.9
Hewlett-Packard Co. Cupertino Division	2115A	$14500 (4K)	2	4	187
11000 Wolfe Road Cupertino, CA	2116B	$24000 (8K)	1.6	3.2	19.2
Interdata, Inc.	Model 4	$10900 (8K)	1	3.6	22.8
2 Crescent Place Oceanport, NJ	Model 5	$15600 (8K)	1	2	22
Multidata, Inc. 7300 Bolsa Avenue Westminister, CA	Model A	$14995 (4K) with tty & disk	.88	4	10
Raytheon 2700 South Fairview Street Santa Ana, CA	704	$ 9750 (4K)	1	2	7
Tempo Computers, Inc. 1550 South State College Blvd. Anaheim, CA	Tempo I	$13800 (4K)	.9	1.8	5.1
Texas Instruments P. O. Box 66027 Houston, TX	TI-980	$16700 (4K)	1	2	6.5
Unicomp, Inc. 18219 Parthemia Street Northridge, CA	Comp-18	$10500 (4K)	.88	1.8	8.1
Varian Data Machines, Inc. 2722 Michelson Drive Irvine, CA	620/f	$10500 (4K)	.75	1.5	3.1
Wang Laboratories, Inc. 836 North Street Tewksbury, MA	3300	$ 7200 (4K) with tty	1.6	4.8	software

TABLE 2 (continued)

MODEL	OPERATING SYSTEMS AND LANGUAGES	I/O EQUIPMENT*	MAX. I/O (KILBYTES/SEC)	MAX. MEM. SIZE
Datacomp. 404	COBOL, basic, timeshare exec.	tty	470	65K
CSI-24	ALGOL-60, basic, FORTRAN IV, timeshare exec.	disk,mtc, mt,cr,tty	3,300	8000K
216	1, 2, or 3 pass assembler, basic	cr,pt,tty, lp,mtc,crt, disk	500	32K
Supernova	assembler, timeshare, basic FORTRAN IV, ALGOL, DOS	tty,cr,pt, pl,mt,disk	870	32K
PDP-11/20	assembler, basic, FORTRAN	disk,pt,cr, tty,crt, mt,pl,lp	1,660	32K
META4	batch monitor, real-time exec., 1130 and 1180 emulator	cr,pt,mt, lp,disk, typ,pl	2,400	65K
2115A	basic control system, DOS, FORTRAN, ALGOL, basic	cr,pt,mt, lp,crt,disk pl,typ, marked card	500	8K
2116B	same as 2115A plus real-time exec.	same as 2115A	600	32K
Model 4	assembler, basic, OS, real-time OS, FORTRAN IV	pt,mt,cr,	500	65K
Model 5	same as Model 4	pt,mt,cr, drum,disk	500	32K
Model A	basic, FORTRAN, OS	cr,disk,lp, mt,mtc,pl	2,000	65K
704	1 and 2 pass assembler, FORTRAN IV, SYMII, basic FORTRAN	cr,disk,pl, mt,mtc,pl, pt,tty	2,000	32K
Tempo I	Tempo I, FORTRAN IV	cr,crt,disk, drum,lp,mt, pt,tty	1,400	256K
TI-980	FORTRAN IV, DOS, real-time, multiprogramming	cr,disk, lp,pt	2,000	65K
Comp-18	1 or 2 pass assembler, basic	crt,mt, pt,tty	2,200	262K
620/f	basic, data assembly system, FORTRAN IV, master operating system	cr,disk,lp, drum,mt,mtc, pl,pt,tty	276	32K
3300	basic, time sharing	disk,mtc, tty,typ	300	65K

* cr = card reader; lp = line printer; mt = magnetic tape drive
mtc = magnetic tape cassette; pl = plotter; pt = paper tape reader;
tty = teletypewriter; typ - typewriter

TABLE 2 (continued)

MODEL	NUMBER OF INSTRUCTIONS	WORD LENGTH (BITS)	NO. PRIORITY INTERRUPTS	NUMBER OF DNA CHANNELS	ADDRESSING TECHNIQUES
Data Comp 404	46	16	15-256	4	
CSI-24	32	24	4-256	1-256	direct, indirect indexed
216	122	16	3-64	0-8	direct, indirect indexed, relative
Supernova	200	16	-16	1 multiplexed	direct, relative
PDP-11/20	400 (handwired)	16	4 expendable	256	direct
META4	27	16	6-32	9	direct
2115A	70	16	8-40	0-2	indirect, partial direct
2116B	70	16	16-48	0-2	indirect, partial direct
Model 4	92	16	1-255	7	direct
Model 5	123	16	1-255	7	direct
Model A	163	16	-384	1-8	indirect, indexed relative
Model 704	74	16	1-16	6	direct, indexed
Tempo I	97	16	4-16	0-7	direct, indirect, indexed, relative, immediate
TI-980	85	16	3-256	1-8	direct, indexed, base register, indirect, relative immediate
Comp-18	31	18	1-64	1-16	direct, indirect, indexed
620/f	135	16	64	16	direct, multi-level indirect, indirect index, pre-index, post-index, immediate, extended
3300	72	8	8-128	1	page indexed

8.3.1 Minicomputer Description

8.3.1.1 Block Diagram

Observe, Figure 1, how a digital computer interfaces with man and the real world. The keypunches, keyboards, teletypes, and telephone networks that operate with digital computers are essentially digital in nature. Through printed characters man interacts with this digital communication. The central processing unit, the mainframe, does all of the logical and arithmetical processing associated with the computer. It utilizes a collection of (Digital) memories--slow paper and magnetic tapes to very fast core memories.

Signals from a non-digital world must be converted into digital parameters for use within the computer system. It may be possible that the input to the digital sensors can be obtained directly.

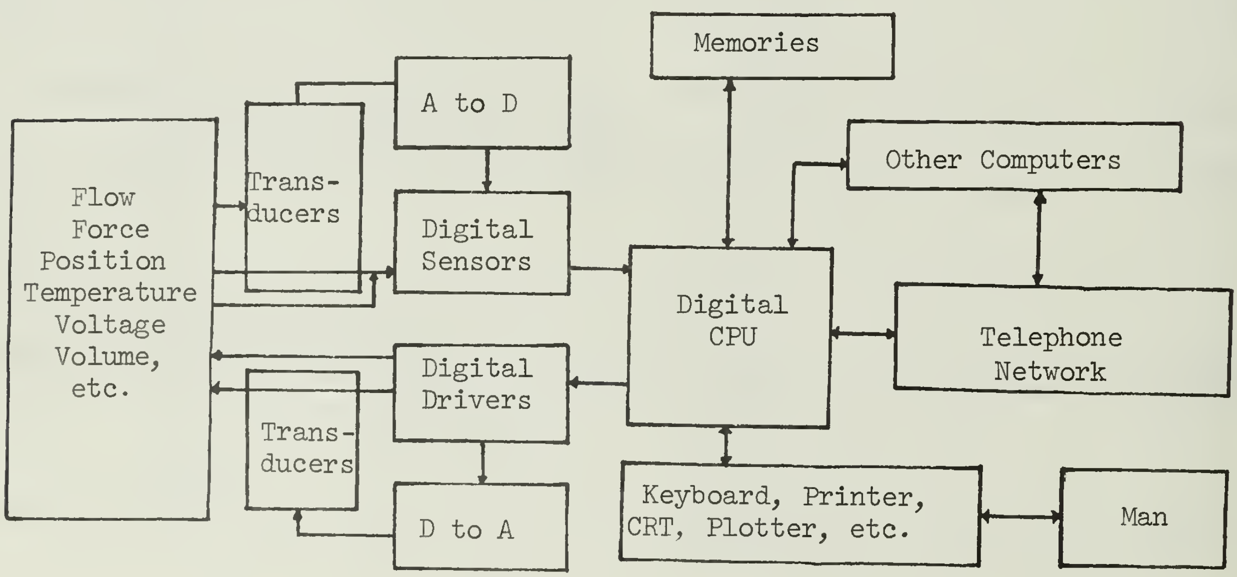

Figure 1. A Digital Computer Interfaces with Man and the World

The computer control unit of Figure 2 coordinates all the other parts of the computer to insure the logical sequencing of operations will be carried out correctly and exactly at the right time. The CCU is the slave of memory (the programmer's program) via the memory control unit. These instructions are interpreted to produce the specific logical sequence required by each program.

8.3.1.2 Memory

The memory modules generally use magnetic storage--thousands of ferro-magnetic cores. For each core, 1-bit or binary digit may be obtained. A word is a collection of these bits: word lengths are 8, 12, 16, 18 bits. Bytes, ordered subset of bits of a given word, may be addressable; a 16-bit word is normally composed of two 8-bit bytes. Further, organization of 4,096 words (4,096 times the word length equals the number of bits) is one memory module; this is referred to as a 4K module. Memory cycle times vary from .5 to 5 micro-seconds.

Normally one or two memory modules are purchased with the larger minis handling up to 64 modules. A normal maximum is 16-4K word modules. There are also 1K and 2K modules. Because of the large numbers of operational registers and the fact that the program of the microprogrammed MICRO Systems MICRO 800 is in a read-only control memory, little if any core memory is required. Micro-programming advantages will follow. The read-only memory may be included as a part of the main memory or as a substitute for or in addition to the computer's read-write memory. Expansion is made easy by plugging a memory module into a pre-wired-to-the memory bus board position.

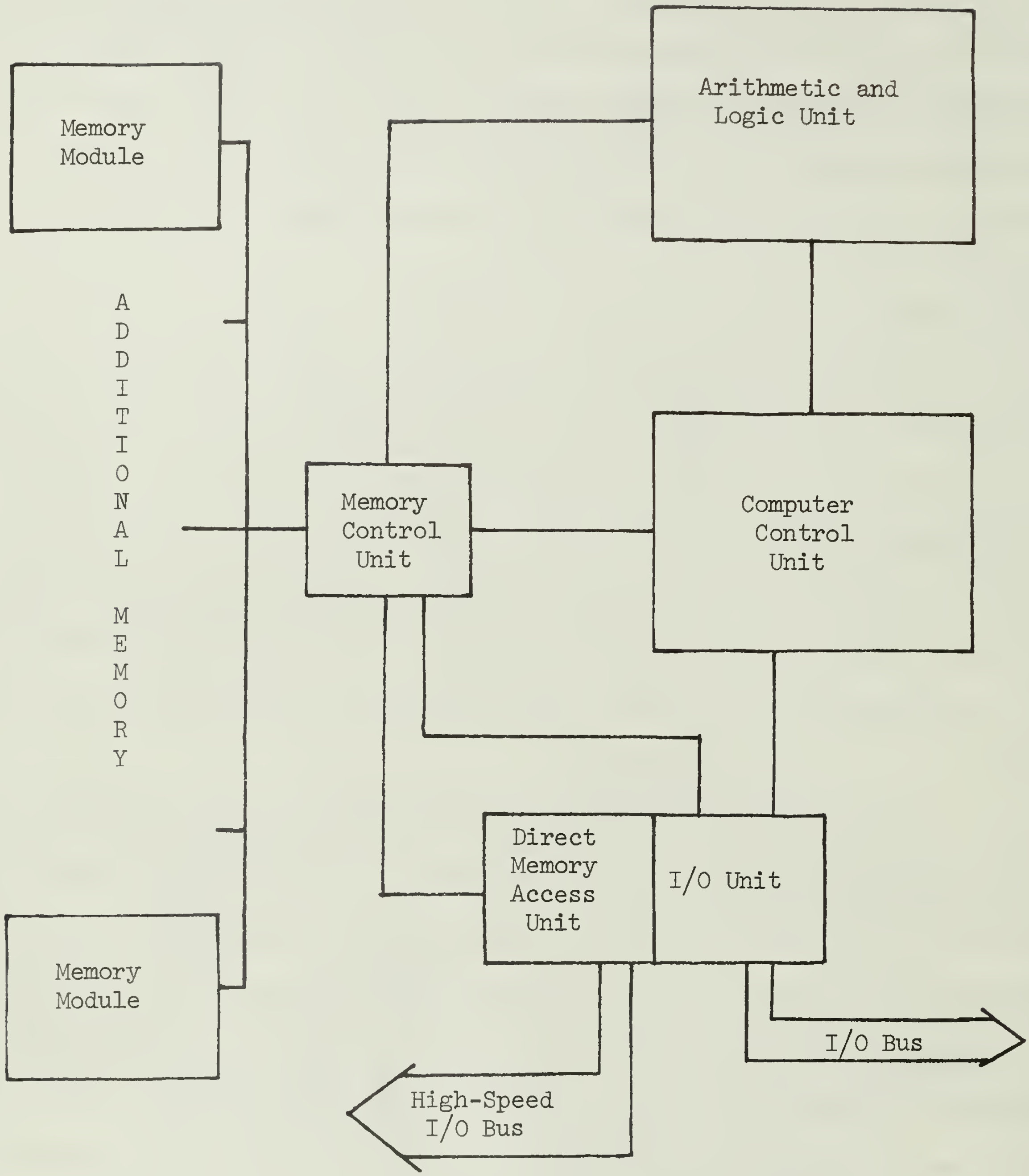

Figure 2. Basic Minicomputer

Under the direction of the CCU, the memory control unit, the master index for insertion and retrieval of information from the new modules, routes memory words to and from all the other units. The memory cycle time noted above is the time it takes the memory word to go through the memory control unit. Obviously, the MCU can function independently of the CCU when (a) several minis share a common memory and (b) when high speed data transfers pass through the direct memory access unit (DMAU). More than 1 DMA controllers may be connected to the same bus. When there are conflicts between the CPU and DMA a priority logic system rules in favor of the DMA. Since normally there exists a single memory bus, the CPU performs memory timing with the timing of instruction execution based on the memory cycle time. Generally there does not exist an overlap of memory operations.

8.3.1.3 Word and Instruction Length

One comment on the 6 to 18-bit word lengths. As the lengths get shorter, the addressing process gets more complicated--more storage cycles are needed per instruction cycle. The price does go down, too, but so does the number of bits available for data addressing/instruction codes. The 8-bit byte addressibility is certainly of high value if computation is kept to a minimum and data is byte oriented (data communication applications). This is because the unit of addressibility corresponds to the data unit and the processor commands are oriented toward the manipulation of characters. This addressing by instruction may reference the left or right bytes of the word or by treating memory as a

class of bytes (not words) each with an address.

While most minis are single address, binary, using the 2's complement to denote negative numbers and most use single-word instruction, others do use two or three word instructions. The 8-bit machines using one or three words per instruction may be considered more flexible than the one-word 16-bit machine instruction. The mini, versatile as it is, has limited storage capacity and computation cycles, thus efficient use of each is required.

8.3.1.4 Addressing

It should be obvious that the word does not have enough bits available to the addressing section to locate each unit of the storage module. With a typical 8-bit addressing operand only 256 storage locations can be pointed to even with the maximum possible 9 bits, only 512 locations can be determined so that data might be transferred to or from the memory. Where a longer memory address of say 16 bits is required, it is calculated utilizing the contents of a register.

By using a double word instruction where the right word of the two is used as the direct address, for a machine of word lengths of 16 bits, 64K storage cells may be directly referenced. It should be pointed out that two memory cycles are required to fetch the instruction and then to compute the address of the operand. By using additional computer resources the range of memory location covered is extended to the entire space. The indirect addressing system consists of reading a memory location which is directly addressable. It uses the data word to

represent the address of data (it is a pointer) instead of actual data; the retrieved contents from the storage location from which it was directed, is treated as the address of an operand to which it points.

This process can be continued into more levels of indirect addressing. Where this data word represents an address of data a special bit must be utilized to indicate an address, otherwise the data word will be the assumed data (operand). Obviously, each time there is a level change, additional memory is required because data word (address) must be processed; i.e., and additional microsecond is added to the instruction execution time for every level of indirect addressing (based on a one microsecond storage cycle of a processor: the usual one microsecond to retrieve the instruction plus the one microsecond to extract the address).

Indexing, either direct or indirect, requires adding the contents of the index register, another central processor register, to the direct or indirect address. In DEC's PDP-11 there is automatic increase/decrease of the index registers' content. When operating with sequential locations this feature proves to be very efficient. Since an additional storage cycle is required if the index register is located in core storage, such minis run slower.

8.3.1.5 Paging

By using only the address bits in the instruction word one may divide memory into fixed areas (pages) whose size is determined by the lengths of the instructions address part, 2^n, n is the number of bits in

the address portion. Normally this is a 256 (or 512) word address. Only two pages can be addressed: the portion of storage numbered (Ø) zero through 256 and the page in which the current command is located--the current page. The computer logic must sense a bit in the command to ascertain whether the instruction refers to direct address or current page. There is no increase in the time of execution. Only one storage cycle is required to obtain the instruction and compute the operand address. Another technique is a scheme which is represented by floating page composed of the 128 or 256 locations on either side of the current instruction. For an 8-bit address length, a relative address could be -128 to 0 to 127 locations from the (current) command location; i.e., given the command location 828, one might make reference to any location within the range 700--955. This is nice for the programmer; he need not concern himself with how his program is positioned/stored within the page boundaries; his only concern is that the memory reference falls within the range established by the floating page centered on the current instruction. One may have to reorganize the code when adding instructions between the operand and the instructions. But with this scheme a page can be swapped out from one location, swapped into another later, and the calculation resumed.

Registers may be addressable (explicit) or buried within (implicit) the system. The first is under the control of the program, while the latter are possibly dependent on other system components upon which the programmer has placed demands.

8.3.2 Minicomputer Organization

In this section we will discuss the organization of a typical minicomputer. Reference the following paragraphs to Figure 3.

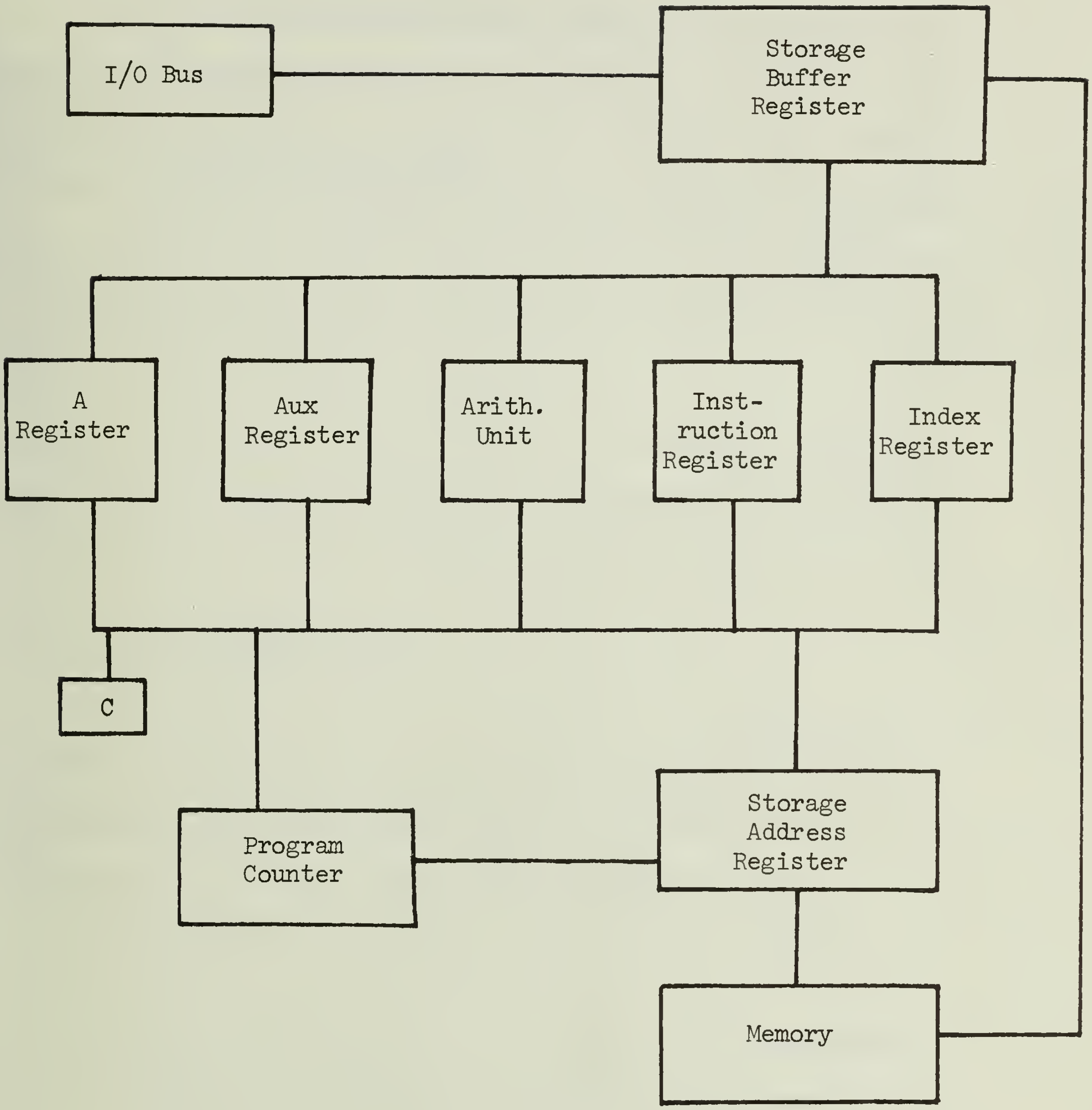

Figure 3. The Organization of a Typical Minicomputer

8.3.2.1 Registers Identified

8.3.2.1.1 Storage Address and Storage Buffer Registers

A pair of registers are necessary. The first is an n-bit wide storage address register. It contains an n-bit pointer to a location in memory to be used as a source or destination. The 2nd of the pair, the storage buffer register, contains the word that will be transferred. Delivery from this bus may be made also to the I/O devices, arithmetic unit, and the programmable registers.

8.3.2.1.2 Arithmetic Register

The arithmetic (A) register is the main operational register. The contents of this register will be transformed by various logical as well as arithmetic operations. The result is returned to the register.

8.3.2.1.3 Carry Register

The carry (C) register, a one-bit register, will hold a bit when carry is required. This bit is used when double precision arithmetic operations are required; i.e., precision extends beyond register A's capacity or the operand length. This bit is also the arithmetic overflow detector register.

8.3.2.1.4 Auxiliary Register

The auxiliary, (Aux), register contains the least significant half of a double-precision word and of the product of a multiply instruction. In conjunction with the A register, it is used for temporary storage and for data shifting.

8.3.2.2 Methods of I/O Transfer

The three methods of I/O transfer are:

1. Multiplexor I/O channel

2. Programmed data transfer

3. Direct memory access

8.3.2.2.1 Programmed Data Transfer

Although the programmed data transfer channel is the slowest, 30,000-40,000 words/sec., it is the most flexible method of transfer (parallel transfer of word or byte) between an I/O bus or one or more of the CPU registers. An interrupt system is required. This method of controlling peripheral devices and checking their status is required whenever the computer must act on input data as it is being received. However, due to the probability of missed data, this is not even recommended for card readers without full card buffering.

8.3.2.2.2 Direct Memory Access

The optional direct memory access feature (DMA) is available for \$2,000-\$5,000 with rates of 1/2 to one million words per second. This allows one or two devices to make block transfers by placing the address of the desired storage hole in the DMA storage address register. With an input to the central processor, there is a signal from the I/O device to indicate a data break. The central processor stops the computation at the end of the current storage cycle. The DMA register are connected to the storage unit and the DMA gets to read or write one cycle. Note then that one storage cycle per word transferred is lost which implies a maximum transfer rate equal to the transfer rate of the storage unit if all cycles are taken.

Finally, note that the devices using this DMA channel are usually controlled through the commands travelling over the I/O bus which also connects the devices. The chaining of block transfers as found on larger computers is not found in minicomputers.

8.3.2.2.3 Multiplexor I/O Channel

The I/O channel (multiplexor) is similar to DMA however 16 or more devices can be active simultaneously. Transfer rates vary within 100-300 thousand words per second. This is not all that good for it is required to have up to three accesses to memory for each word transferred. (One of the memory cycles is to decrement the word count and check for zero; a second memory cycle is to obtain the memory address and increment it and the third memory cycle is to transfer the data). The card reader, punches, line printers, slow magnetic tape make effective use of this.

8.3.2.3 Interrupt Systems

I/O operations for some devices may be handled via the interrupt system, but it can do other things as well. The hardware is sensitive to the occurrence of certain "interrupt conditions" or "events" which require that the present calculation be deferred and the processor decide which event took place, and go to an appropriate routine, do something about the event, and then resume the deferred calculation. When the presence of an interrupt condition is recognized, the hardware must do the following:

1. store program counter
2. decide, by means of hardware or software, which interrupt condition of highest priority is present
3. disable interrupts of lower priority
4. process the interrupt
5. restore program counter and then enable interrupts of lower priority

8.3.2.3.1 Single-Level Interrupts

Whenever a single-level interrupt occurs, the control unit looks to a unique storage location to get the address of the interrupt service routine. No other devices can be serviced, no interrupts will be replied to until the program processes the first. Obviously, many instructions must be used to differentiate between the devices, which are on-line, that transmitted the interrupt.

8.3.2.3.2 Multiple Level Interrupt System

Up to 256 levels of hardware interrupt priorities are available in some minicomputers. Each interrupting peripheral device has a priority number. On some machines this may be set, device by device under program controls. There is also a register in the CPU called the priority level register. When any I/O device gives an interrupt request this is only granted if its priority level is higher than that held in the priority register. Having interrupted, the priority is raised to agree with that of the device being serviced. Likewise, on return from interrupt, the priority level is lowered to that of the routine which was last interrupted.

8.4 The Minicomputer's Peripherals

8.4.1 General

The low cost of the mini-main frame is one thing, the cost of interfacing the mini to other hardware and the cost of peripherals is yet another very demanding requirement in minimizing the cost of the operating system. With the shift from the large to the smaller user, or if you will, from the $1,000/month down to the $100/month user has come a redistribution of cost. Percentage of 70%-30% central processor to peripherals have now been reversed to 30%-70%. This

is due not only to the decreased costs of core memories but the desire to use high cost peripheral devices on the small system to make it available to more people. Also, hardware costs are closely related to labor costs which have increased greatly. Note too, that due to automation, electronics costs have gone down. Whenever required, programming function are not done by hardware. The programmer gets to show his prowess in preparing the software. A software package for I/O has been prepared for the user and supplied as a subroutine. Note that controllers for the perpheral devices consists of a single printed circuit board. No longer is it across the room or in the next cabinet but often this circuit board is within the same chassis as the CPU and its memory. The DEC PDP-11 treats registers in the peripheral controller as addressable memory. They cause these controllers to interface directly with the computer's memory bus. This provision is for peripheral device-memory transfers for direct memory I/O transfers as well as CPU-memory and CPU-peripheral device transfers.

Until the latest generation of peripherals, the device controller designers have had a great variety of interface circuits with which to communicate. Now with the heavy use of integrated circuits a DTL or TTL gate is becoming the standard peripheral interface with the minicomputer. Using integrated circuit line drivers and receivers (at a higher cost) gives performance superior to the balanced twisted-pair transmission lines. Using these low impedence differential drivers and differential amplifier receivers with common mode rejection, in conjunction with twisted-pair transmission lines, cable lengths in excess of one hundred feet are possible.

9. PERIPHERALS

What the world needs is faster teletypes! Their present low cost does supply the minis I/O requirement. It serves as a slow output printer (14 minutes to dump 4K words of memory) and as a cheap form of storage for output from the computer. This unit serves as a keyboard for program input although at a rate of 10 characters per second. Note Figure 4 for a quick ready reference comparison for data I/O. Historically, teletypes have been used for the preparation of punched paper tape which is read by the computer at a later time. Now the trend is to connect all teletypes to minicomputers and do on-line creation, editing and execution of user files.

9.1 General Comparisons

While three times more expensive than TTY, an optical tape reader and a high speed paper tape punch will read 30-40 times faster and punch 10 times more; again, the paper tape may be prepared off-line on the TTY and then read into the computer by the higher speed reader. On very modest systems paper tape is used for temporary storage, for example for a multi-pass assembler. Paper tape while easily damaged when rewinding is very reliable even when damaged. Often it can be repaired and the data recovered.

Before continuing to review the established peripheral devices, let us turn to punched cards which are relatively costly but much easier to edit and update. Even with the advantages and an obvious future, with changes like IBM's 18 x 32 hole (matrix) card, the card with the greatest

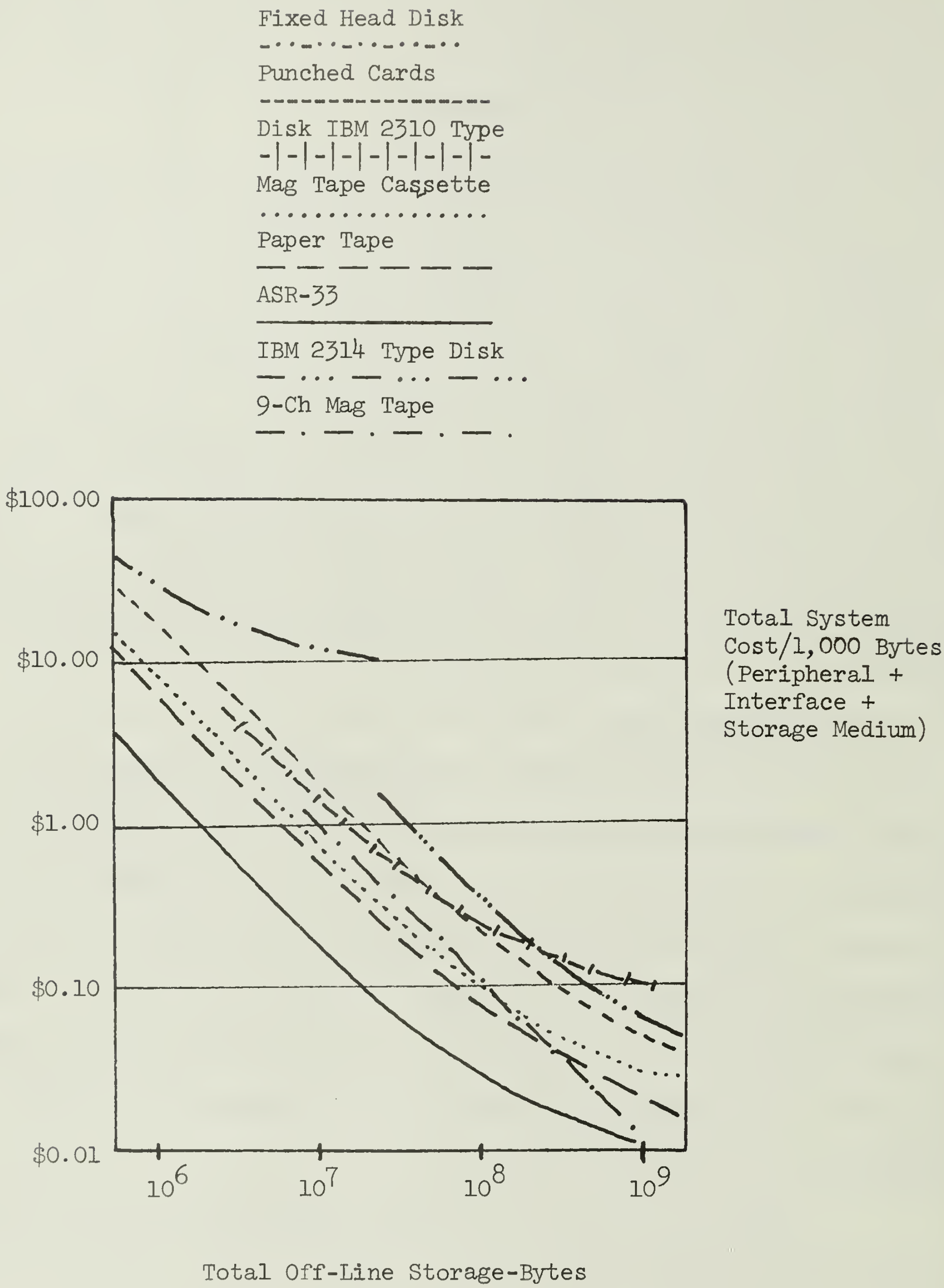

Figure 4. Total Cost/1000 Bytes of Off-Line Data Storage vs. Amount of Off-Line Storage for Minicomputer I/O

future surely must be mark sense. There are mark sense card readers which will read not only punched cards but also those prepared with visual markings from a pencil or pen. It would be nice to get off the teletype or keypunch or even the faster, more reliable typewriter. This will be reconsidered later.

The 9-channel magnetic tape units, IBM format, 800 bpi, allows interchange of data between the minicomputer and the EDP systems. Higher expense brings about freedom of generating the tape off-line and 1600 bpi recordings.

A "system 3" type, removable million byte disk cartridge, with a non-removable million byte disk has an average access time of about one hundred milliseconds. The minicomputer is no longer I/O bound but limited by the software to maximize the mini-disk combination. Again, off-line input hardware is too high except in timesharing. A typical disk storage unit consists of 32K words capacity, 18 milliseconds access time, transfer rate of 10^5 words per second, but not removable. Therefore for different or larger amounts of data, more units are required.

Although convenient, the magnetic tape cassettes are not interchangeable, in large part, due to the lack of standardization. To reduce data loss, redundant recordings are often made. This is due to a reliability deficiency.

With faster and more complicated, yet smaller and cheaper, computers available, the mill-stone about the man/computer system is the information interface between the human user and the machine. We want to transfer information into and out of the machine with as little effort

(physical and mental) as possible. Teletypewriters are woefully inadequate due not only to their slow speed but also their rigid format. Alphanumeric output at 10-15 characters per second is well below human scanning speed, and input and output of graphic data is cumbersome. A better console, a display device capable of handling characters, points, and lines in a free format is needed. A stand-alone unit connected to a standard telephone line as TTY's do should make use of the full available data rate that phone lines offer.

Interactive graphics is the "ultimate" in information exchange procedures between machine and man. It is unsurpassed in the rate and quantity of easily digestible information it can pass to the human. When the computer can communicate in pictures, lists of numbers become graphs, structures can be illustrated, etc. Note the obvious use of graphics in computer applications where the real world is modeled--process control, simulators, etc.

9.2 O(C/M)R or Sensing

Optical Mark Reading (OMR) operates on the basis of reading marks that have been entered on a form in a prescribed location (and usually a short straight line). The OMR scanner seeks out such marks and reads them based upon their location on the page. This differs from optical character recognition (OCR) whose scanner reads based upon the shape of the character. It differs from Mark Sense which is a system which reads the form, similar possibly to OMR in that the form was "marked", but with an electrographic pencil. The user places marks, at his option, at some of various fixed places on the card, and the mark sense reader detects the

presence of such marks by passing an electric current from one end of the mark to the other.

Mark sensing: marks sensed electrically
Mark reader : marks read optically

Forms are of two basic formats: single copy forms; continuous or cut or as 51 or 80 column tabulating cards. Forms will range in size from 3 1/2" x 4" to 8 1/2" x 11". Card forms vary from 4 1/4" x 7 3/8" for the 51 column cards to 7" x 3 1/4" for 80 column cards.

"Inks" used depend on the response system used; response systems may be visible, infra-red, or ultra-violet.

An item that must be closely checked is the extremely tight tolerances which some readers must maintain with respect to the distance between the timing marks and the mark read field. The IBM 1230 allows a tolerance of only ± 0.005". Similar tolerances may exist with respect to skew.

Due to the extremely high cost, my only comment on OCR is that a $3000 per month OCR reader attains a breakeven point when reading 17,000 bills per day. Thus if sufficient amounts of input data are processed, OCR probably is not only faster but also cheaper than the keypunch. A 30-unit keypunch installation including labor is $14,950 per month. For page reader, fourteen typewriters and typists and five proofreaders cost $10,775 per month. This reader "reads" a regular typewritten sheet at a rate of about four lines a second (110 characters per line). Or, if you will, it would read 180 pages each minute.

9.3 Graphic Processing

The importance of graphic processing is divided between the

importance of vision in transmitting data to the brain (a picture is worth a thousand words) and the increased high speed of computer devices. A video display makes sense out of pages of character printing which the programmer would have to interpret. Now interpretation can be made in a moment and alterations promptly made. Graphic data simply stated is an "efficient" (from the user's point of view--not the computer's) input/output technique in which information is exchanged between the user and the computer in the form of "pictures". Note here that a desirable adjunct to graphic output is graphic input. The "pen", an electronic pointer with which data may be entered directly onto the CRT screen, is certainly advantageous. True symbiosis of man and machine has each doing what each is good at: man provides the random creativity while the computer does the routine, programmable tasks and stores a complete record of transactions in retrievable form. A system's use is in direct proportion to the degree of cognizant interaction it provides the user; i.e., two basic requirements are memory and speed. Compared to the 10-15 characters per second by a teletype the 120-300 characters per second for a CRT is a welcome relief. Costs for CRT's however run to $50,000 and they tie up more than one line to the computer in some cases. Another apparent disadvantage is that there is no hard copy. A further comment: although it is important that a hard copy be available, with suitable software aids, it is not required at the local console for most applications. At Project MAC, over 90% of the TTY output paper went directly into the trash basket. The required copy is generally for record purposes (grading, etc.)--a need which can be filled by a central hard-copy generator.

There are three categories of implementation. Random scan techniques are most common in both alphanumeric and line-drawing applications. (Depending on the line generation technique, draw times are from tens to hundreds of microseconds.)

Considering the cost trade-off, the relatively slow storage tube, lacking the interactive continuity because there is no way to update only a portion of the screen, has a response time of milli-seconds. It may take many seconds to update a full screen.

Video scan displays are normally alphanumeric applications. For applications requiring generation and frequent update of alphanumerics, the video scan display is an inexpensive and reliable tool. These displays, I/O terminals, are flexible, fast, and easy to modify and format data. Features which would be desired are: nondestructive cursor; character and line insertion and deletion; and display generation under computer control. The alphanumeric CRT is more restrictive than the graphic in that it does not allow underlining or leaving blanks for answers in the problem format. (An underline is considered a character. Having fixed character positions prohibits the display of two characters in the same position simultaneously.)

CRT displays with graphic capabilities appear best suited to instructional applications. The direct random positioning of characters permits superscripts and subscripts, underlining, and presentation of such things as long division or complex fractions.

Some of the features considered desirable for this type of device are: a touch-sensitive projector screen such that when the student

identifies, by touch, specific parts of a display, because the device is under computer control, the correctness of the response can be determined; (repeat) dual processor configuration (i.e., with computer control); real-time clock and pushlist subroutining permitting time-shared and re-entrant code; hardware multiply and divide; at least one index register; a minimum of 8K core and 16-bit word length; 10 x 10" minimum display size; long persistence phosphor. And, if you will, borrowing from the Plato III, superimpose "a large number" of slides on the screen. (Plasma Display Panels will help provide these features when available on the market.)

10. REMARKS

10.1 Assumptions, Delivery, and Credibility

Minicomputers are taking over many of the tasks that have been done by hardwired logic systems or by the large computers. So that one might choose a minicomputer depends on how the minicomputer will be used. What tasks are to be performed? Its use will determine the choice. A priority list can be constructed and each manufacturer can be rated according to how their computer matches these priorities. There is never to be the assumption that a feature exists unless specifically listed; these would be such items as cables, power supplies, or cabinets, etc. Minis are marketed by others than the manufacturer. This may affect purchase for the manufacturer may not have developed additional peripheral interfaces which add a certain flexibility: XDS-CF-16 is a CA-216. Check the manufacturer's credentials by contacting previous customers. They can provide an index of delivery, credibility and reliability.

By categorizing minicomputer applications, it is hoped that important features will be exposed. The first is the stand-alone computing, laboratory, and monitoring applications. It should be quite obvious that in university and research laboratories stand-alone computing applications typically occur. Laboratory and monitoring applications represent an extension of stand-alone computing applications where usually a variety of transducers, sensor, multiplexors, and analog-to-digital converters are connected to the basic stand-alone system. Generalizing, this mini-system is composed of direct I/O. devices, usually teletypes, but

paper-tape readers and punches or card readers and line printers might be added. The file storage facility includes cassettes tape along with the magnetic tape, disk, or drum storage devices. In a laboratory/monitoring situation there are many tailormade monitoring I/O devices; such as digital voltmeters, counters, multiplexors, oscilloscope displays, plotters, special-purpose transducers and sensors, etc.

In choosing a minicomputer mainframe, begin by determining the types of I/O equipment desired. Select the applicable language(s).

An integrated circuit design application might not only require a strong arithmetic unit and also a paper tape reader/punch, but also a CRT display with pen light. Estimate production, problem-solving and software development times. The relative amount of time to be spent in short problems or frequently run production programs affect the choice. What commands are available may limit the system's computational capabilities. An efficient arithmetic unit with short add and multiply times, floating point multiply and divide, and double-precision operations are desired. Mathematical and utility programs such as diagnostics, text editors, and debug programs aid in automated problem solving. The Varian Data Machines 620/i is used by the U.S. Government in many departments. The multiprocessing computer system, the MOD COMP III/70 by Modular Computer Systems is used in development and testing laboratories for engines (reciprocating). Parameters include torque, speed, fuel consumption, temperatures, pressures, etc.. The Data General Super-nova has made the business market in the educational system.

Let us look in on how a Hewlett-Packard general-purpose 2116B minicomputer with 16 K memory is used to monitor experiments, cardiac dimensions, pressures, in conscious dogs and then derive dynamic ventricular performance data. With a variety of implanted sensors, the investigators measure, monitor, and record the primary cardiac variables of physical dimensions, pressures, flow rate, ECG, and heart rate of conscious dogs, acquiring the data under computer control. After a selection is made of the segment of data that is of particular interest, the data are used as source information for rapid calculation by the computer of the parameters descriptive of dynamic cardiac performance such as cardiac output, flow, wall stresses, etc.

The minicomputer permits the on-line computation, printout, and display of the measured and derived quantities. It also permits the simultaneous measurement, in the intact animal, of the variables for a moment-to-moment assessment of ventricular performance.

Many manufacturers are making their products for use as components in larger, more complex systems. In particular, minicomputers can be used as component testers, numerical control machines, transfer machines, etc. By controling I/O devices which service large computers, they reduce the processor cost by performing simple data manipulation tasks, control sequences and assembly procedures.

Minimum and maximum data rates for both host and peripherals should be specified in addition to normal transfer rates. Buffering may be needed to smooth deviations in data transfer rates. If the data is to be both input and output, then the minimum I/O rate must be

twice the peak transfer rate. The minicomputer must have a short cycle time so that it can respond to all peripheral/host computer within the specified time. Consider carefully the priority interrupt structure and the minimum time expended in processing the interrupt. Scratch pad memory, general purpose registers and multiported memory minimize data loss and the failure to respond to its host under interrupt conflicts. These features promote flexibility. Investigate the communications code and control signals of the devices before choosing the mini as a device controller. One indication of interface flexibility of a particular model is off-the-shelf availability of the needed interfaces. While "moving" commands are very important, mathematical abilities are slight: error detection or other statistical analysis may be desired.

Let us now consider the minicomputer as a data concentrating system where a number of low-speed input devices such as TTY and other human I/O terminals are connected. The mini then concentrates all of this data to transmit it efficiently to some other device, usually a larger computer. Consider also the use of the minicomputer to facilitate intercomputer data transmission.

We will consider the addition of a card reader, line printer, and a communication interface to a minicomputer to build a remote batch terminal for a large central processor. Mass storage devices are not always included but one or more indirect I/O devices in addition to the communications hardware are. There may be an interface to a host computer. There may be data set controllers to service various common carrier data sets.

Consider momentarily a series of free-standing minicomputer systems, each of which may be used as a terminal for a larger computer. One might want to tailor each to some specific situation (and each so designed for use by less sophisticated personnel). Since the mini is used on site, there is no need for more expensive data communication facilities. The mini can, as the on-site computation is completed, act as terminals, condensing the data and forward relevant parts over telephone lines to the central computer facility for further data processing and management information. By taking advantage of a party line telephone cost and by the reduced number of telephone lines, communications costs are cut. A system built around Data General Corporations Nova cut the telephone bill of one firm from a potential $10,000 per month to $1200 per month.

10.2 Reflections from Logicon 2 + 2

Consider the dependence of four linked minicomputers each operating independently and efficiently on its specialized task. The Logicon Inc.'s 2 Plus 2 lays claim not only to increased throughput, reduced turnaround time and lower cost performance, but also the elimination for line termination, multiplexer equipment, or "front end" processors. Operator interferance is reduced and so is the number of human errors.

The hardware system is based on four subsystems:

1. An I/O and control subsystem for system control; this mini performs all system scheduling and I/O management tasks. It controls the information flow to the other subsystems.

2. Swapping is under the control of the extended memory subsystem mini.

3. The computational subsystem is for process execution (user) even those functions not economically done by the control processor of the control subsystem.

4. For peripheral device handling, the communications and mass storage subsystem, controls disk and tape storage units and multiple communications lines.

Seven major components comprise the Logicon 2 + 2: the computational, I/O and control, communications and mass storage, and extended memory hardware sybsystems; and the programming, operating, and application software systems. The logical organization of the Logicon 2 + 2 is illustrated in Figure 5.

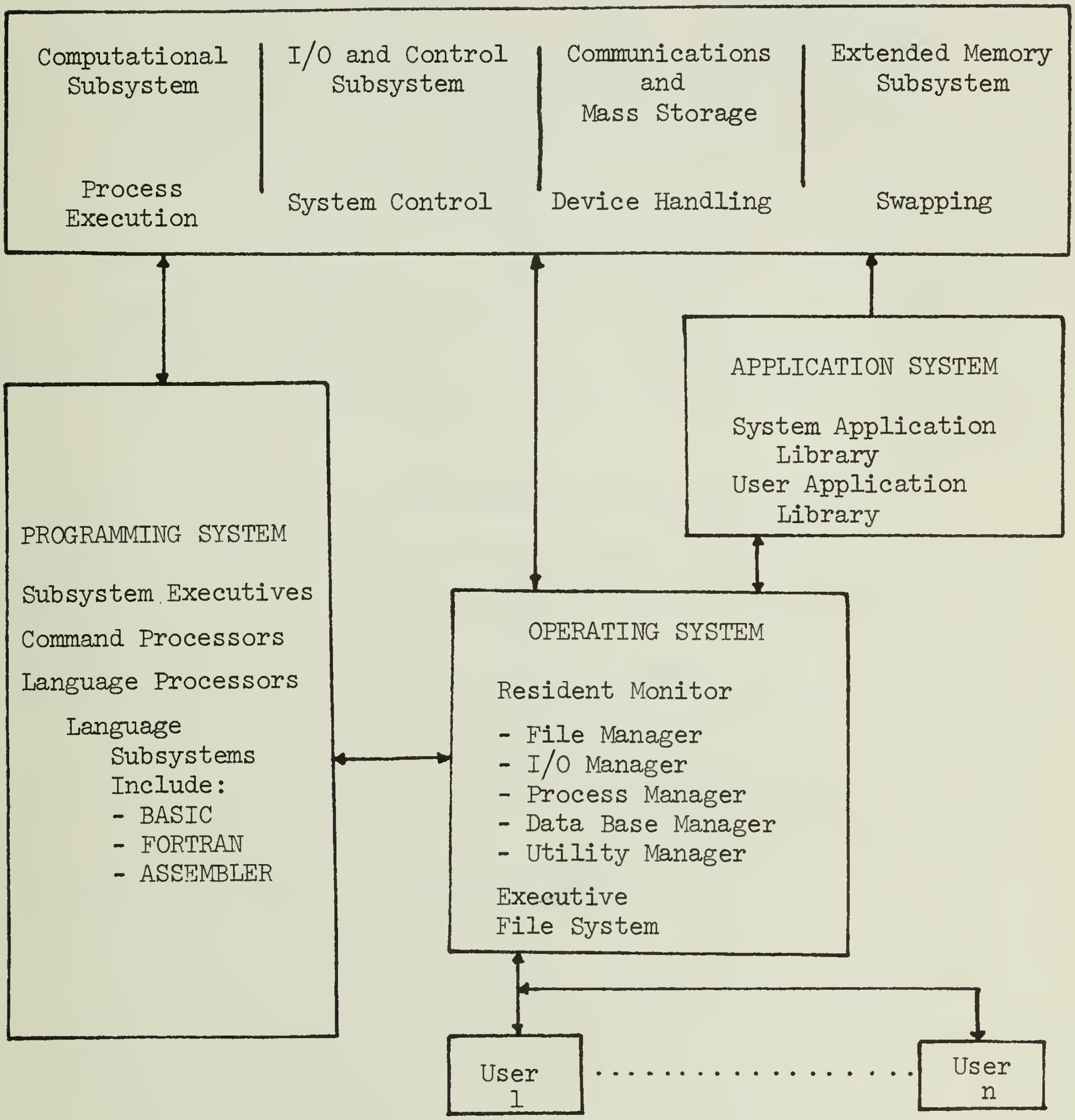

Figure 5. Logicon 2 + 2 System Logical Structure

11. WHERE FROM HERE

11.1 Microprogramming

Microprogramming should play a major role in future minicomputers. While it will be assumed that the concepts of microprogramming are known, the objective of this chapter will be to discuss advantages of microprogramming. A microprogrammed computer employes a stored program repertoire for the control unit rather than fixed wiring--the control unit is not fixed but instead it is programmable.

The control sequencing is implemented by a control storage element and a counter to address the current microprogram location. The control storage contains the microcommands which are decoded and executed. The microcommands perform elementary operations; they are executed in one clock step, so that a time sequence of control signals is generated by executing a series of microcommands from the control storage. Since the microprogram location counter can be loaded from the processor as well as from the microcommand register, this permits the microprogram sequence to be modified by information from the processor, memory, or from the I/O as well as by jump microcommands in the control storage. Refer to Figure 6.

The microprogrammed computer has two levels of stored program control:

1. at the micro level using microcommands in the control storage

2. at a macro level using instruction words in the main memory to specify the operations performed by the control unit

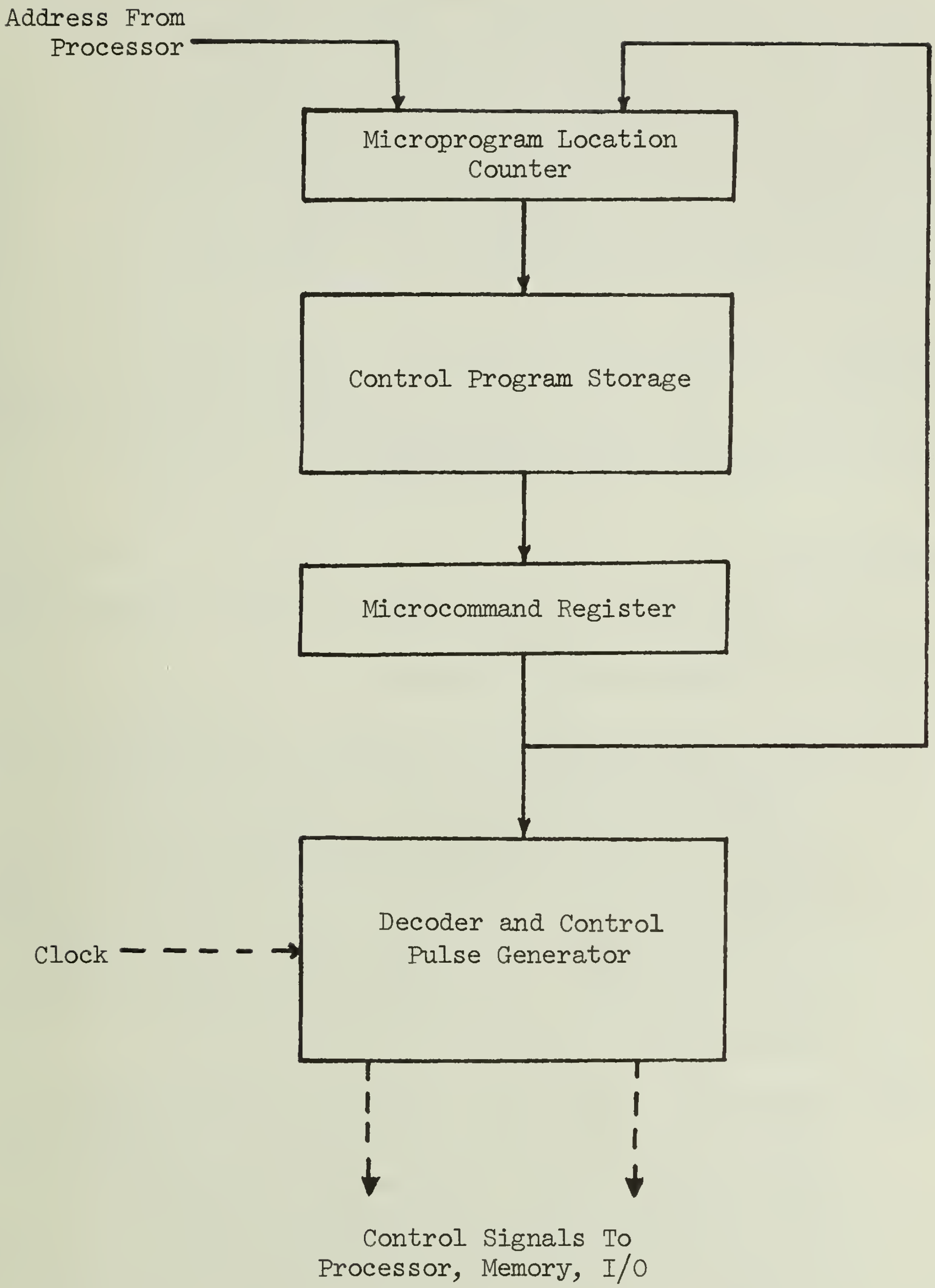

Figure 6. Microprogrammed Control Unit Organization

Since the control unit is programmable, it is possible to code an entire application program at the micro level. The main memory would contain no instructions as is the case with the MICRO 800. It should be apparent that the programmable control unit gives great flexibility not only for internal operations but also for external I/O and control functions. This flexibility can be used to great advantage in interfacing the computer to other equipment in a system environment. Selecting the proper approach invariably derives hardware cost savings in a system application.

11.2 Applications

There are five ways to approach application to system functions. Each has its own advantages and disadvantages.

1. Micro level application programming--Where maximum throughput performance is required, the application can be programmed directly with the microcommand set. All commands are stored in read-only memory. The core memory is used for storage of data and perhaps variable parameters used to specify functional operations at the micro level. This approach permits a direct processing or control operation to be executed at each clock time. One disadvantage is that the read-only memory program cannot be altered. This problem can be solved by storing variable control parameters in core memory.

2. Macro level programming using the standard software level which may be more familiar than microprogramming. Microprograms enable the small machine to simulate the performance of another computer. By using some of the read-only storage, the computer can be provided with a repetoire of instructions. Throughput speed is sacrificed in favor of greater flexibility in altering the application program. Since macro instructions are not executed at the same speed as the microcommands. (Diagnostics, Teletype operating system)

3. Macro level programming using supplemental problem-oriented macro instructions to enhance its performance and throughput. These macro instructions are implemented by adding special subroutines to the standard firmware in read-only memory. (Convolutions, math algorithms, threaded list operations, etc.)

4. Macro level programming by emulation of another general-purpose computer. Justification for this approach can include: familiarity with another machine; an existing investment in application software, availability of specialized software programming aids. Using this approach, the minicomputer is microprogrammed to execute instructions of another computer directly from core memory without prior language conversion. The I/O hardware is designed when necessary to emulate the simulate system. An obvious advantage to this approach is replacement of obsolete hardware without sacrificing existing software.

5. Emulation of a special-purpose computer such as signal processors, data compressors, telemetry decommutators.

11.3 Advantages of Microprogramming Performance in System Applications

While microprogramming can be used to derive significant performance advantages over the fixed control computers, whether or not full use needs to be made of this facility depends upon the application. When a small-scale computer is applied in high-volume situations, unit cost of hardware will usually far outweigh non-recurring development costs. For a dedicated system application, spare capacity computer performances is of no great value unless it can be used to reduce hardware costs by absorbing additional system functions into the internal time-shared logic. Here microprogramming can be used to full advantage, and nominal one-time costs to develop problem-oriented microprograms can result in significant reductions in unit costs of hardware.

A fixed instruction set computer utilizes core-stored assembly language subroutines to implement problem-oriented programs. Most of these computers have a fixed word length compatible with core memory. Isolated single precision arithmetic operations may be relatively fast. Instruction execution times are dependent not only upon the core memory cycle time but also by the operand addressing mode and other factors.

In the short word length machines, these limitations almost always severely effect program execution speed.

A microprogrammed computer using a high-speed read-only memory is particularly well suited where fast problem-oriented operations are required. The basic data flow can be through multiple file registers (hardware flip-flops) rather than core memory. All basic information and data transfers are under control of the high speed read-only memory through the file registers. For many control applications, core memory is not needed in the system, but can be added where buffering is required for data or for the traditional software sequences. Direct memory access can be employed for high-speed data. If used for general purpose requirements, the core contains software to address the macro held in read-only memory in such a manner as to simulate a general purpose computer with an instruction set and a word length defined by the microcommands in the high-speed ROM firmware.

How fast is execution time of a microprogrammed computer? Digital Scientific Corporation's META 4 has a 35 nsec ROM. The microprogrammed computer can emulate fixed instruction set computer but with some loss in speed for a comparable memory cycle time. Memory efficiency is improved because of optimum word length utilization.

Microprogram control simplifies most I/O interface requirements, with the timing and buffering accomplished internally without additional hardware or software. The firmware approach is

less expensive than hardware control and can completely eliminate the need for I/O software subroutines. High speed micro operations often permit serial techniques to replace parallel word handling to eliminate costly I/O buffers.

While memory efficiency is improved because of optimum word length utilization, a significant speed pay-off occurs when additional problem-oriented macros are added to a basic instruction set. Multiple precision arithmetic and complex macros which replace entire software subroutines in core can be several times faster than software subroutines and yet require only a small fraction of core memory allocation.

Many system problems can be solved initially by a conventional software approach using a general purpose instruction set. Augmenting this by problem-oriented macros has been noted. As system requirements change, extra demands placed on the computer may exceed any spare capacity in the machine. For such unexpected situations, a fixed instruction set computer must be replaced by a larger, more expensive machine--often at considerable cost in engineering and system down time. With a microprogrammed computer, more problem-oriented functions can be implemented in ROM to improve system performance. These changes do not require replacing the computer a rather simple change or modification of ROM circuit boards in the computer can create a dramatic gain in throughput capacity. Software modifications are minimized since the macro program is reduced rather than expanded by addition of the problem-oriented instructions.

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